AN INVITRO STUDY TO EVALUATE THE FRICTIONAL CHARACTERISTICS AND SURFACE TOPOGRAPHY OF TWO DIFFERENT ARCH WIRES COATED WITH SILVER NANO PARTICLES USING PASSIVE SELF LIGATING BRACKETS

DISSERTATION

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in partial fulfillment of the requirement for the degree of

MASTER OF DENTAL SURGERY

BRANCH V

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SREE MOOKAMBIKA INSTITUTE OF DENTAL SCIENCES, KULASEKHARAM

ENDORSEMENT BY THE PRINCIPAL / HEAD OF THE INSTITUTION

This is to certify that the dissertation entitled "**An In Vitro Study To Evaluate The Frictional Characteristics and Surface Topography of Two Different Arch Wires Coated with Silver Nano Particles Using Passive Self Ligating Brackets"** is a bonafide research work done by **Dr. Surya. R. Krishnan,** under the guidance of **Dr. P. Anilkumar,** M.D.S, Professor and Head, Department of Orthodontics and Dentofacial orthopedics, Sree Mookambika Institute of Dental Sciences, Kulasekharam.

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LIST OF ABBREVIATIONS

Abbreviation	Expansion
AgNP	Silver Nanoparticle
TMA	Betatitanium
SSUC	Stainless steel uncoated
BUC	Beta titanium uncoated
PVD	Physical vapor deposition
SEM	Scaning electron microscope
SSC	Stainless steel coated
BC	Beta titanium coated
SS	Stainless steel
nos	Numbers

ABSTRACT

Introduction:

Orthodontic tooth movement during space closure may occur in two different types of mechanics: sliding mechanics and frictionless mechanics. In sliding mechanics, friction is generated by the relative motion between archwire and the bracket, sliding mechanics is widely used in fixed appliance therapy. The rapid progress in the field of biomedical engineering has resulted in various surface modification methods to improve the overall performance of the biomedical metallic materials. Coating the orthodontic metallic wires on their surfaces using different materials and techniques are among the strategies that have shown to improve both the biological as well as mechanical properties. The present study involved the coating of rectangular TMA and stainless steel archwires with silver nanoparticles, via the physical vapor deposition – DC magnetron sputtering method. The objective of the study is to reduce the frictional values of the archwires during the sliding mechanics for faster tooth movement, shorter treatment duration and to prevent root resorption. This study is also done to evaluate the surface characteristics of the silver nanoparticle coated archwires, in combination with passive self-ligating stainless steel brackets having MBT prescription so as to ascertain the relation of the surface quality of the archwires with that of the friction that is being generated during the procedure.

Methods:

The two types of orthodontic metallic archwires were coated with silver nano particle using physical vapor deposition method –DC magnetron sputtering and thickness measured using profilometer.

All frictional tests were conducted in a dry state on Instron 3345 testing machine. Friction testing was done using passive self-ligating stainless steel brackets, MBT prescription. Surface characteristics was tested by subjecting the samples to scanning electron microscopy, prior to and after the friction testing. The sliding resistance and surface characteristics of the AgNP coated and control archwires were analyzed.

Results:

The measurements were obtained for the mean frictional values for the uncoated stainless steel, coated stainless steel, uncoated TMA and coated TMA orthodontic archwires. It clearly indicates that there is reduction in frictional values for the AgNP coated TMA archwires when compared with uncoated counterparts and also with the AgNP coated stainless steel, archwires. The surfaces of the AgNP coated TMA and stainless steel archwires were smooth and even.The uncoated TMA surfaces showed rough surface as concurrent with other studies. No significant surface alterations upon SEM evaluations of friction tested archwires coated with AgNP was found.

Conclusion:

The AgNP coated TMA archwires showed statistically significant difference in their frictional values, when compared with the uncoated archwires. It could be recommended for improved frictional properties, better surface characteristics to be used in sliding mechanics. No significant reduction in the frictional values of AgNP coated stainless steel archwires for both dimensions used in the study was noted, instead higher frictional values were obtained which indicates that there is no need to coat stainless steel archwires with AgNP.

Key words:

Silver nanoparticle coated archwires, friction, passive self-ligating brackets.

INTRODUCTION

The aim of orthodontic treatment is to move the teeth to a targeted position by the application of forces to them. During orthodontic treatment archwires wires, components of fixed appliances are used to apply forces to the teeth. In order to move teeth, the wire should be able to slide through the bracket, resistance to sliding counteracts this ability of the wire.[1] The advantages of sliding mechanics are decreased chair side time, less complicated wire bending and patient comfort. But the disadvantage is that it results in the generation of frictional forces at the bracket-archwire interface, which decreases the speed of the tooth movement. It has been found that approximately 12 % to 60 % of the applied force was lost due to resistance to sliding as stated by Kusy et al.[2]

Friction is the resistance to motion that occurs when one solid body slides or tends to slide over another. It is described as a force acting parallel to the direction of motion. Friction is present in all forms of sliding mechanics, such as retraction of canine into the site of extraction, leveling and alignment where the archwire should slide through the brackets and tubes. Friction exists in two forms: static friction and kinetic friction. Many procedures has been used to quantify sliding resistance between arch wires and brackets, such as a weighted basket or bucket, force gauge, dynamometer, and a universal testing machine.[3] Several factors affect the resistance to sliding such as: size & shape of the wire, the bracket type, the bracket and the wire material, the angulation of the wire r to the bracket, the ligation mode, whether the environment is dry or moist. The magnitude of friction depends largely on the nature of the material, force acting and the surface roughness. During mechanotherapy that involves in the movement of the bracket to the wire, friction at the bracket-wire interface may prevent the achievement of optimal force levels in the supporting tissues. Therefore, a decrease in frictional resistance is beneficial to the response of the hard and soft tissue. Various experimental studies have proved the influence of frictional resistance between the brackets and the archwires. Several mechanical and biological factors may modify the frictional force generated during orthodontic sliding mechanics.[4] The sliding resistance has three components: friction, static or kinetic, occurs due to contact of the wire with surfaces of the bracket; binding, it is created when the tooth tips or the flexing of the wire occurs, so that there is contact between the wire and the corners of the bracket; and notching, occurs when the wire permanently deforms at the wire-bracket corner interface. This often occurs under clinical conditions.

Self-ligating brackets were introduced in the mid-1930s in the form of the Russell attachment by Stolzenberg, which was intended to reduce ligation times and improve operator efficiency.[5]

Self-ligating brackets are ligature less bracket systems. Passive ligating brackets have less resistance to sliding when compared to active self-ligating brackets.[6] Therefore passive ligating brackets were selected for this study with a purpose to reduce the friction. Moreover self ligating brackets have reduced friction compared to conventional brackets.[7] Other advantages include full and well secured wire ligation, much better sliding mechanics and possible anchorage conservation, less treatment time, longer appointment schedules and fewer appointments. With respect to the archwires, different types are commercially available, out of which the stainless steel and beta titanium archwires were selected for this study.

In metallurgy, stainless steel, also known as inox steel is a steel alloy with a minimum of 10.5% chromium content by mass. Stainless steel is notable for its corrosion resistance properties. Austenitic stainless steels are widely used for manufacturing orthodontic brackets and archwires. The austenitic 18-8 stainless steel type is the most widely used archwire. It contains chromium and nickel content of approximately 18% and 8%, respectively. Stainless steel wires have good corrosion resistance and a lower bracket-wire friction than other types of wires.[8] This friction could be furthur lowered by usage of nanotechnology as stated by Katz et al.[9] Hence stainless steel was selected for this study.

Beta titanium wires are also known as titanium-molybdenum alloy (TMA), introduced in 1979 as an orthodontic archwire. Titanium is an allotropic material and beta titanium exist in the body centred cubic structure shows high corossive resistance (B phase). TMA archwires demonstrate good formability, joinability, resistance to corrosion and a biocompatible material. It had a flaw - the coefficient of friction was higher than the other orthodontic alloys.[2] As a result, higher orthodontic forces should be applied to achieve the desired tooth movement and overcome resistance to sliding. Thus the TMA wires have a good combination of strength and flexibility but exhibits slow rate of tooth movement during space consolidation.[10] Usually TMA archwires are used in frictionless mechanics and stainless steel archwires are used in friction mechanics. TMA wires when compared with stainless steel wires, has lower force magnitudes, a lower elastic modulus, higher spring back, greater resilience, a lower yield strength, good ductility, lower hypersensitivity, good biocompatibility. They have a good combination of flexibility and strength.[11] So through coating procedure the mechanical property of the TMA wire could be increased. Hence TMA archwire has been chosen for this study.

The two different types of archwires are chosen for this study with regard to whether an improvement in their frictional properties could be noted after coating of the surfaces with AgNP. Two different dimensions 0.017 x 0.025” inch and 0.019 x 0.025 inch of each type of archwires are used in the study so as to ascertain and evaluate the play of the archwires in the slot of the brackets, as the thickness of archwires would be increased after the coating procedure is done.

Friction is a major challenge to be controlled in the orthodontics, during tooth movement. A low coefficient of friction is desirable for space closure.[12] This is overcome by, coating the surface of the metallic orthodontic materials. The surface topography can affect both the aesthetics & performance of the working orthodontic components .Surface roughness is an essential factor in influencing the effectiveness of arch guided tooth movement, which is in turn related to the coefficient of friction.[13] The application of coatings can modify the surface of the material which plays one of the major role in generating friction. Various coating techniques and materials have been used with the objective of improving the surface qualities. Thus coatings are one among the strategies to improve both the mechanical and biological properties of the archwires that are selected for this study.[14-16]

Previous study by Arash et al, states that electroplating of silver on stainless steel brackets did not show any reduction in friction, but an increase in friction was noted. In his study, it was mentioned about the possibility of reduction in friction once PVD coating of silver was done on the stainless steel brackets which is to undertaken, in future studies.[17] Hence in the present study, PVD coating of silver at nanometric level on two different types of archwires - stainless steel and beta titanium is decided to be carried out.

This study focusses on the utilization of physical vapor deposition – Dc magnetron sputtering method for the deposition of AgNP on archwires. Physical sputtering is a technique that involves in the vaporization of atoms or molecules from a solid surface by momentum transfer from the atom sized particles that are bombarding and energetic. The particles are predominantly ions of a gaseous material accelerated in an electric field.[18]

Krishnan et al coated beta titanium archwires with titanium aluminium nitride and tungsten carbide/carbon using physical vapour deposition methods of coating and evaluated the frictional properties, surface morphology and load deflection rate. It was found that the tungsten carbide/carbon archwires had reduced frictional properties and better surface characteristics than the uncoated archwires.[19]

Ryu et al coated silver – platinum alloys to orthodontic stainless steel to test the antimicrobial properties and found that during orthodontic treatment coating provided good antimicrobial activity.[20]

Introduction of the concept of nanotechnology in 1959 by renowned physicist Richard Feynman, has found its applications in diverse fields including medicine and dentistry. A recent innovation in the form of metal nano particle coating has been introduced, that could significantly reduce the friction of archwires. Studies have shown that the nanoparticle coatings on orthodontic archwires reduces the friction in sliding mechanics. Nano technology is manipulating matter at nanometer level. A nanometer is 10^9 or one billionth of a meter.

The orthodontic appliances harbors a unique environment for colonization of microorganisms as they adhere onto the morphological irregularities on the surfaces of the fixed appliances and thereby it becomes difficult for patients to maintain their oral hygiene adequately.

With the advent of nano technology, silver nanoparticles (AgNPs) have been synthesized, and they have shown potent antimicrobial properties. AgNPs have also been applied in several areas of dentistry and therefore it's incorporation might be utilized in coating the archwires in order to reduce the coefficient of friction between the archwire-bracket interface. Silver nanoparticles are clusters of silver atoms that range in diameter from 1 to 100 nm. Recent evidence suggest that silver nanoparticles have potent anti-inflammatory effect and accelerates wound healing AgNP has also been proved to be biocompatible with mammalian cells, suggesting that its application on dental materials does not represent a threat to human health.[21]

Nano silver is one of the leading nanotechnology materials and products for its unique antibacterial properties and anti-inflammatory effects, so it has been selected for this study. Today there is a reasonable good understanding of the nano silver toxicity and it is dose dependent. The proper tribologic properties of nanoparticles have been suggested that when an angle is created between the bracket and the wire, resulting in greater resistance to sliding, the nanoparticles function as a solid lubricant on the surfaces, thereby reducing frictional forces. Hence it could clinically improve the rate of tooth movement during the retraction & space consolidation procedures, thus minimizing anchorage loss, root resorption and improving the overall treatment period.

Various studies of other coatings on archwires have shown to significantly reduce friction. Diamond like carbon films were deposited on stainless steel and nickel titanium archwires and the friction was found to be reduced. The results of the study by Muguruma et al, stated that diamond like carbon coated wire with self ligating brackets was good for tooth movement in orthodontics.[22] Coating of archwires with inorganic fullerene like nanoparticles like tungsten disulphide on stainless steel archwires have shown to reduce the friction upto 54% stated by Redlich et al.[23]

The archwires coated with silver nanoparticles to reduce the frictional values might have good potential in the orthodontic treatment. Hence the attempts of this study focuses to evaluate the friction, surface characteristics of silver nanoparticle coated archwires in comparison to its uncoated forms. Thus the study aims to provide an increase in the level of comprehensive oral health of the patient.

AIMS & OBJECTIVES

1. To evaluate and compare the frictional force values of two different uncoated and AgNP coated orthodontic archwires - stainless steel and beta titanium of two different dimensions (0.017 x 0.025 and 0.019 x 0.025 inch SS) and (0.017 x 0.025 and 0.019 x 0.025 inch TMA) using passive self-ligating brackets.

2. To check the surface topography of two different archwires before & after the friction test.

REVIEW OF LITERATURE

Stoner et al (1960)[24] focusses on the analysis of forces used in orthodontic practice and describes about the various methods of loops that were contoured well to obtain absolute and more effectual control in 3 dimensional plane of space.

Burstone et al (1979)[4] put forth that beta titanium wire had low stiffness, high spring back, formability and weldability which indicates it's important application in many of the clinical situations as a new material for orthodontics.

Frank CA et al (1980)[25] concluded that for tooth movement to take place, force that is generated must overcome the static fictional forces. The kinetic frictional forces produced as a result of the movement must be lower than the orthodontic forces applied which in turn should be greater than the resistance exerted by the periodontium as a whole.

Burstone et al (1980)[11] in his patentship stated that beta titanium alloy wire could be used as the force imparting component in Orthodontics. It provides , three fold improvement over 18-8 staintless steel wire in case of load defection rate and two fold increase in maximum elastic displacement while providing a low modulus of elasticity and optimum low level force magnitudes. The wire finds important utility in orthodontic, prosthetic and surgical fields.

Kusy et al (1981)[26] concluded that beta titanium wire was a good intermediate archwire as its composition and cross section affects the elastic properties during tooth movement. Stainless steel was ideal for the later stages of orthodontic movement of teeth due its stability. Both stainless steel and beta titanium had good corrosion resistance. Beta titanium was found to be expensive than stainless steel.

Thurow et al (1982)[27] stated that the frictional resistance is increased as slot of the bracket become narrow, as there occurs more binding of the archwire to the bracket. The increase in friction is influenced by the bracket design and the material.

Burstone et al (1983)[28] reported that stainless steel had the greatest bending moment than beta titanium and nickel titanium, while the nickel titanium and beta titanium had the greatest spring back ability.

Garner et al (1986)[29] concluded TMA alloy had its advantage with excellent formability, weldability, low hypersensitivity and elastic modulus than stainless steel. But TMA was susceptible to fracture during bending, had increased surface roughness thereby increasing the friction than the stainless steel. Thus the archwire composition may or may not increase the friction during tooth moment. Improvement in the archwire material produced easier tooth movement by the reduction in friction.

Kusy et al (1987)[30] concluded that when nickel titanium and beta titanium were tested in both 3 and 4 point bending , the elasticity of nitinol appeared to have a varying results while for the TMA wires, the modulus of elasticity was independent of the wire size. As the wire cross sectional area increased, the elongation also increased making it more suscepibile to fracture duing bending.

Baker et al (1987)[31] reported that in the wet condition by the introduction of artificial saliva, it reduces the frictional resistances between the archwire and bracket than in the dry condition. Archwire dimensions also determines the magnitude of the frictional force that is produced during the movement of the teeth.

Kusy et al (1988)[32] studied sixty orthodontic archwire size combinations from six manufacturers in the bending and uniaxial tension test. Results on the mechanical properties of stainless steel orthodontic archwires showed that the wire diameter had some influence on the frictional values.

Kapila et al (1989)[8] had reviewed stainless steel and beta titanium based on their mechanical properties. It was found that stainless steel could be welded or soldered, had low surface friction, environmental stability, stiffness, resilience, low cost, biocompatible. While beta titanium had good formability joinability, adequate springback, average stiffness, could be welded but a flaw - coefficient of friction was higher. The mechanical properties of these wires were evaluated by tensile, bending and torsional tests. Optimal use of these wires could be made by proper selection of the appropriate wire type and size.

Tidy (1989)[33] found that the friction was proportional to the applied load and inversely proportional to the bracket width. He investigated the resistance to friction during movement along a continous archwire. It was concluded that the beta titanium arch wire had two to five times greater frictional resistance than the stainless steel archwire.

Kusy et al (1990)[34] reported that the surface topography plays a significant role in determination of the treatment progress and esthetics of the orthodontic components.

Berger et al (1990)[35] stated that during sliding mechanics, mode of ligation plays an important role in frictional assessment**.**

Kusy et al (1992)[15] To reduce the frictional coefficient on beta titanium archwires, nitrogen ion implantation was done and its effect on the archwire strength was evaluated invitro. Both the static and dynamic friction was found to be reduced when titanium was ion implanted into polycrystalline alumina and nitrogen into beta titanium wire, when compared with the unimplanted ones.

Tselepsis et al (1994)[3] the study measured the dynamic frictional force of sliding between archwire and bracket combination. The following factors were selected for the study: arch wire material, bracket material, bracket-to-arch wire angulation and lubrication (artificial saliva). All were found to have a significant influence on friction. Friction increased with bracket-to-arch wire angulation. Lubrication significantly reduced friction. A range of 0.9 to 6.8 N frictional force was recorded. Inference was that polycarbonate brackets showed high friction than stainless steel brackets. The forces observed suggest that friction have a significant influence on the amount of applied force required to move a tooth in the mouth. Therefore, arch wire and bracket selection may be an important consideration when posterior anchorage is to be considered.

Kusy et al (1997)[2] found in his study that 12% to 60% of the applied force was lost due to resistance to sliding, which affected the efficiency of treatment outcome.

Kusy et al (1997)[36] stated that an ideal material has not yet been found, archwires should be selected within the context of their actual use, according to the treatment need. Betatitanium wires have more range of action than stainles steel wires, which are more affordable than the former. Betatitanium had the higher coefficient of friction when compared with the stainless steel wires.

Bouravel and Fries (1998)[37] stated that surface roughness of the archwires is an important factor that determines effective tooth movement. Surface roughness of beta titanium was measured and found to be approximately 0.21um, as it was found to be in contrast with earlier studies reporting high frictional loss. It also influences the esthetics of dental materials, the corrosion behaviour and biocompatibility. Surface roughness extreme variability might be due to manufacturer's negligence to upgrading of the quality standards.

Pizzoni et al (1998)[38] reported that the self-ligating bracket had lower friction than conventional bracket at all angulations. The forces acting in a continous arch system largely depended on the bracket design, wire material and wire cross section. Round wires had lower friction than rectangular wires and beta titanium wires had higher friction than stainless steel wires. Self-ligating brackets, closed by the capping of a conventional design, showed a significantly lower friction than self-ligating brackets closed by a spring design. So the design had a role in determining the friction.

Kula et al (1998)[14] conducted a study in vivo as to determine whether ion implanted beta titanium would bring about the space consolidation. It was measured intraorally at each month interval. There was no significant difference between the rate of closure of beta titanium wires with and without ion implantation. The space closure rates were same as that of stainless steel ones.

Swann et al (1998)[39] stated the types, advantages, disadvantages, procedure details and it's benefits in thin film coating applications regarding the magnetron sputtering technique.

Kusy and Whitley (1999)[40]The friction was divided into 3 components a) static or kinetic fiction b) Binding which results in contact between the wire and bracket corners, as the wire flexes or tooth tips c) Notching causes a permanent deformations of the wire at the bracket - wire interface. It was concluded that 3 components play a vital role in determining the friction.

Zhang and Guo (2000)[41] compared and evaluated the effect of nanostructured diamond like carbon coatings and nitrocarburizing on the biocompatibility and frictional properties of stainless steel archwires. The study concluded that, the coating and nitrocarburizing increased surface hardness and reduced friction with improvement in biocompatibility. Excellent corrosion resistance and good elasticity was also achieved.

Brantley et al (2001)[42] Beta titanium wires showed slow rate of tooth movements during canine retraction and space consolidation than the stainless steel and cobalt chromium wires. Various coating techniques to reduce the friction with beta titanium archwires were carried out, but proved to be successful only in a limited range.

Thorstenson et al (2001)[43] stated the comparison of self ligating brackets to conventional brackets with regard to resistance to sliding in both wet and dry states .It was found that self ligating brackets had reduced frictional values than the conventional brackets in both dry and wet states.

Sahagian et al (2001)[44] patented the document stating that the dental article is first coated with an adhesion layer, then later a friction reducing coating is applied to create a hard inert layer on the device. This reduced the adhesive wear and friction on the device and thereby improving the frictional properties. Iridium reduces the friction between the bracket and the wire when applied as a thin coating to orthodontic titanium molybdenum alloy (TMA) wires. Both the overall coefficient of friction and the "stick-slip" was significantly reduced. The iridium coating did not increase the amount of friction, and coated brackets have other advantages, such as improved appearance and wear properties.

Kusy et al (2002)[45] in his review article put forth the evolution of orthodontic biomaterials from the past dated from 1863 to the present. He elaborated about the early contributors and the changing paradigm of tooth movement associated with the new material innovations in the field of orthodontics that influenced in bringing about the reduction in friction.

Rossouw et al (2003)[46] he stated about what is friction, loss of applied force,it's contolling factors were explained in the experimental canine retraction model. He concluded that because of the variability of the factors in the biological parameters in patients and variety of orthodontic appliances, the clinical frictional values may be less than that of what will be tested under the laboratory conditions.

Nishio et al (2004)[47] reported that beta titanium had higher statistically significant frictional resistance than the stainless steel. The frictional values were directly proportional to the angulation between the archwire and the bracket.

Tecco et al (2005)[48] he evaluated the influence of friction generated by conventional and self ligating brackets with archwires on sliding to resistance when tested on a specialized model. He found that the coefficient of friction was low.

Higher frictional force values were seen as the dimensions of the wire increased with all the brackets used in the study.

Katz et al (2006)[9] studied and evaluated frictional properties of orthodontic archwires coated with tungsten disulpluide an inorganic fullerene, similar to molybdenum disulphide. In both wet and dry states, the results showed a statistically significant reduction in friction. Sliding at different tilt angles were observed. The release of particles from the coating into the tribological interface caused the reduction in friction by the formation of a solid lubricant film on the archwire. The fullerene particle helps in the easy sliding of the archwires and thereby helpful in space consolidation procedures.

Verstrygne et al (2006)[12] He evaluated the material characteristics of the beta titanium and stainless steel archwires and stated several differences between the two .The archwires were tested for their dimensions, bending, tensile and surface properties. He concluded that the corrosion behaviour is very closely related to the surface roughness and irregularities.

Tecco et al (2007)[10] studied and evaluated the frictional resistance generated by conventional stainless steel (SS) brackets (Victory Series), self-ligating Damon different stainless steel (SS), nickel-titanium (NiTi), and beta-titanium (TMA) archwires. When comparisons among the different types of archwires were done, the thicker rectangular archwires (0.019 × 0.025 inch TMA, 0.019 × 0.025 inch SS, 0.019 × 0.025 inch NiTi) showed a significantly higher level of frictional force when compared with 0.016 × 0.022 inch NiTi. Slide ligatures showed significantly less friction than the other groups.

Walker et al (2007)[49] studied the effect of fluoride on the mechanical and surface quality of beta titanium and stainless steel orthodontic wires and concluded that corrosive changes in the topography was noted which lead to the decreasing of the functional unloading mechanical properties of both the wires, thereby contributing to prolonged treatment time.

Kim and Cho (2007)[50] reported the experimental study on the antimicrobial effects of silver nano particles and found that silver nanoparticles could be utilized effectively as growth inhibitors of various microrganisms due to it's antioxidant activity on the peptidoglycan layer of the bacterial species.

Miles et al (2007)[51] compared the active and passive self ligating brackets and explained the advantages and disadvantages. He also presented new concepts in regard to the future of SL brackets: combination bracket system, hybrid system, and selective usage.

Kusy et al (2007)[52] studied the thermal and mechanical properties of beta titanium, stainless steel and nickel titanium archwires. He stated that each archwires had its own unique properties that influence the friction.

Redlich et al (2008)[23] studied the effect of archwires coated with inorganic fullerene like nanoparticles like tungsten disulfide, found that it substantially reduced the friction values during orthodontic tooth movement. As the frictional load increases, the wearing of the archwire occurs due to the deformation of nanoparticles and it gradually wears away allowing low friction to result in the sliding mechanics, by getting pressed in between and coated at the interface of two contacting surfaces. The coating is based on an electrodeposited nickel film that is impregnated with inorganic fullerene-like nanospheres of tungsten disulphide. Up to 60% of reduction in friction was found between coated rectangular archwires and self ligating brackets when compared with the uncoated ones. The coated archwire surfaces were then tested by SEM equipped with an energy dispersive analyser and also by X-ray powder diffraction, taken before and after the friction test .This coating not only significantly reduces friction of the archwires but it also maintains this low value during the duration of the tests when compared with the archwires coated with nickel film without the nanoparticles.

Budd and Dasakalogiannakis (2008)[53] investigated the tribological behaviour of four commercially available self ligating bracket systems in vitro and found that Damon 3 bracket consistently showed lowest resistance to friction. Passive self ligating brackets produced less resistance to friction which may result in decreased control of the archwires when compared with actively ligated system.

Trevisi et al (2008)[54] discusses about the self ligating bracket to be passive , allowing low levels of forces during biomechanics , ensuring good 3 dimenional control, reduced friction between archwire and bracket.

Mahieu et al (2008)[55] concluded in his study about the importance of sticking coefficient of the target material onto the substrate in the PVD coating procedure and explained about the role of distance in the target to substrate during the coating procedure.

Ehsani et al (2009)[56] studied the amount of frictional resistance expressed between orthodontic self ligating brackets and conventionally ligated brackets in vitro and found that self ligating brackets produced low friction compared with conventional brackets.

Burrow et al (2009)[57] reviewed critically about the importance of friction in orthodontics and enumerated various factors influencing friction**.** He concluded stating that friction has to be controlled for effective tooth movement to take place.

Manu et al (2009)[58] Self-ligating brackets eliminates or lowers the frictional values of ligation at the bracket-wire interface. He compared the effects of stainless steel, nickel-titanium, and beta-titanium archwires on frictional forces of passive and active self-ligating brackets with a conventional bracket. Both static and kinetic frictional forces were tested and he found that it was less for both the passive and active designs when the conventional brackets are compared. Maximum values was noted for the beta-titanium archwires and significant differences were observed between nickel-titanium and stainless steel archwires. With the passive or active self-ligating brackets, stainless steel archwires did not produce a significant difference, but differences were significantly shown with nickel-titanium and beta-titanium wires. When nickel-titanium and beta-titanium wires are used for guided tooth movement, passive appliances lowered the sliding resistance than the active appliances.

Huang et al (2010)[59] reported that shortened chair time and slightly less incisor proclination to be the only significant importance of self ligating systems over conventional systems.

Stefanos et al (2010)[60] in this study it was to evaluate the frictional resistance between active and passive self ligating brackets and 0.019 x 0.025" stainless steel archwire during sliding mechanics by using an orthodontic sliding simulation device. Passive self-ligating brackets have lower static and kinetic frictional resistance than do active self-ligating brackets with 0.019 x 0.025" stainless steel archwires.

Chaloupka malam and Seifalian (2010)[61] had reviewed in the study that nanosilver due to its potent antibacterial activity is in the interest of biomedical applications. It is useful in healing of wound and in inflamatory condition. Recently its antiviral properties have been elaborated by Elechiguerra et al (2005). However the full potential of their technology has to be carried out in vivo.

Stephanie et al (2010)[7] systematically reviwed the efficiency, effectiveness and stability of treatment with self ligating brackets when compared with conventional brackets.Shortened chair side time and less incisor proclination apper to be only significant advantages of self ligating systems.

Brauchlia et al (2011)[6] compared the frictional behaviour of several self ligating brackets , both passive and active self ligating brackets were compared with that of the normal brackets, with and without tipping force moments and in combinations with different archwires dimensions. The inference was that resistance to sliding between brackets and archwires is highly dependent on the experimental set up. As active and passive self ligating brackets showed different behaviours and hence direct conclusion from in vitro studies to the clinical situation cannot be drawn, as too many other factors also influence the overall treatment progression. Passive self ligation reduces the friction mostly in the sliding mechanics, than the active self ligation.

Muguruma et al (2011)[11] Conducted a hypothetical study that diamond like carbon coating does not increase the frictional properties of orthodontic wires and concluded that these carbon coatings reduces the friction. Self ligating brackets that were used in the study showed that the friction was less compared to the conventional brackets.

Farronato et al (2011)[62] reported the effect of teflon coating on the resistance on sliding mechanics, which resulted in low friction. The wires had good mechanical properties and were of esthetic value. Teflon-coated archwires were tested using frictional resistance tests by means of a universal testing machine and compared with conventional uncoated wires. Twelve types of archwires with round and rectangular sections (0.014, 0.018, and 0.018 × 0.025 inches) and of different materials (stainless steel and nickel–titanium) were tested with two passive self-ligating brackets (SmartClip™ and Opal®) and one active self-ligating bracket (Quick®).Teflon-coated archwires produced lower frictional levels than their respective uncoated archwires. The best frictional results were found with a combination of Teflon-coated archwires and Quick brackets.

Doshni et al (2011)[63] studied the static frictional force values and the importance of surface roughness in relation to frictional values when different archwires and bracket combinations were used. It was found that ceramic with gold-palladium bracket slots and coloured TMA archwires were a better alternative to stainless steel during space closure.

Pacheo et al (2011)[64] evaluated the sliding to resistance of self-ligating brackets .He concluded that they exhibited low friction than conventional brackets.

Khalid et al (2012)[65] reported in his comparison study on sliding resistance between stainless steel and beta titanium archwires with self ligating stainless steel, titanium, stainless steel brackets that significant increase in friction was found with combination of titanium brackets and reduction with stainless steel self ligating brackets.

Krishnan et al (2012)[19]studied the frictional properties, surface morphology and load deflection rate with the looped design of two newly developed archwires , Titanium aluminium nitride and Tungsten carbide/carbon via physical vapor deposition , coated on beta titanium orthodontic archwires. He compared these with uncoated wires and found that Tungsten carbide/carbon coated wires had reduced frictional properties with low load deflection rate and better surface characteristics. The newly developed TiAlN and WC/C PVD coated beta titanium orthodontic archwires might be useful during the space consolidation stage of orthodontic mechanics, be it friction or frictionless mechanics.

Amini, Rahini, Shariati and Aghamohamadi (2012)[66] studied the comparison about the surface roughness of two types of orthodontic archwires from four different manufacturers via SEM - Profilometry study. They stated that the manufacturers need to improve the quality of the product by giving more attention in order to reduce the surface roughness and thereby to improve the efficiency and safety of orthodontic treatment .Tests were conducted on 35 specimens of seven different orthodontic archwires , Titanium-nickel archwires from OrthoTechnology, American Orthodontics , All-Star Orthodontics and Smart Technology. SEM-EDEX determined the composition and surface characterisation of each archwire in the study.

Pacheco et al (2012)[1] in the study concluded that resistance to sliding mechanics is multifactorial. New innovations technically by altering the design and surface treatment has developed new low friction materials. The cost was an effective factor and the need to increment the orthodontic material research has been gaining more importance. New orthodontic materials had to be innovated in order to reduce the clinical limitations of the research studies.

Santiago and Vargas et al (2013)[16] reviewed the methods of coatings and surface treatments on biomaterials used in orthodontics. Poor friction control, hypersensitive reactions and metal ionic releases are few of the disadvantages of the metallic alloys utilized in orthodontics. To overcome these, various techniques of coatings have been tried in the clinical practice. Physical vapor deposition is one of such process used in the coating of metallic alloys.

Silva et al (2013)[67] evaluated the thickness of the coating of four different brands of rectangular archwires that were aesthetically coated. The surface properties and stability of the coating was tested after subjecting it to oral exposure for twenty one days. It was compared with the conventional nickel titanium and stainless steel ones. The coated archwires were of low aesthetic values and detoriation was found.

Singla et al (2013)[68] conducted a research on the evaluation and comparing the efficacy and effectiveness of three different self ligating systems - Smart clip, Damon 2, In-ovation. It was found that Smart clip had better treatment completion time, less number of appointment visits in clinical significance, not in statistical significance. But the quality of orthodontic treatment results was the same for all the three brackets.

Ravichandra et al (2014)[69] reviewed in his article the different materials used for manufacturing orthodontic wires and their properties along with the clinical implication. Recently developed super stainless steel having advantage over titanium wires have also been mentioned in his article.

Muguruma et al (2014)[70] investigated the effects of the third order torque on the frictional values of self ligating brackets and reported that the design of the brackets influences the static friction. It was also noted that while using self ligating brackets, if the torque increases there was an increase in the friction also.

Raji et al (2014)[71] concluded in the study that bacterial plaque accumulation on the coated wires is less than that is on the uncoated wires. Different types of polymer coatings could be done on orthodontic wires to avoid the load of microbial plaque accumulation .

Divband et al (2014)[72] studied the effect of zinc oxide nanoparticle coating on nickel titanium orthodontic wires with respect to sliding mechanics and he concluded that zinc oxide nanoparticle coating reduced the coefficient of friction and SEM study confirmed a homogenous deposits of the nanoparticles on the archwires.

Jacobs et al (2014)[73] determined the amount and severity of EARR (external apical root resorption) after the orthodontic treatment with self-ligating (SL) and conventional (Non-SL) brackets. Differences regarding the rate of extraction cases, appointments and the treatment time were evaluated. It claimed to be the largest study showing that there is no difference in the amount of EARR, number of appointments and extraction rate, when comparison between the conventional and self-ligating brackets was done.

Reddy et al (2014)[74]conducted a study randomly comparing the efficiency of 5 different ligation systems (Elastomeric ligature ,stainless steel ligature, leone slide ligature, passive self-ligation, active self-ligation) over the duration of resolving mandibular crowding . It was found that self ligation brackets were found to be more efficient than the conventional ligating brackets during initial levelling and aligning stage.

Ahmed et al (2015)[75] stated the importance of friction in the biomechanics of orthodontics. He illustrated whether friction is a boon or is it to be avoided in the orthodontic therapy.

Castro et al (2015)[76] in his review stated that the efficiency of orthodontic treatment, relied on the design and condition of orthodontic wires. Corrosion of orthodontic wires is dependent on the acidicity level of the oral cavity and presence of flouride ions in the mouth wash and other agents. The effect on stainless steel and beta titamium wires might have a negative effect in orthodontic treatment time . More over other additional assays and test should be undertaken for better utilization in clinically apt conditions.

Aloysius et al (2015)[77] concluded that the beta titanium archwires treated with ion implantation showed improvement in the frictional properties and surface characteristics of aesthetically coloured archwires.

Juliana et al (2015)[21] reviewed the study that silver nanoparticles prevent or reduce the formation of biofilm over dental material surfaces. Lu et al have studied the titanium implants that has been incorporated with different concentrations of silver nanoparticles and found that silver nanoparticle coatings with low amounts of silver were favoring more growth of the osteoblast. It has also been proved to be biocompatible with mammalian cells. However more studies need to be done in order to assure the antimicrobial effect without increasing the cytotoxicity levels.

Arash et al (2015)[17] concluded in his study that silver when coated on stainless steel brackets via electroplating method showed increase in friction. He had recommended that coating of silver on stainless steel brackets via PVD might decrease the friction.

Chaudhary et al (2015)[78] in his article reviewed that nanotechnology has a special stand in the field of orthodontics as it has the capability to shorten the orthodontic therapy, as well as treating the after effects of the contemporary various treating phases. The nanodentistry helps in the maintainence as well as upgrading the oral health by precisely puting forth nanomaterials.Biotechnology and dental nanorobotics which plays a very important role in orthodontics as well as in the field of esthetics has been the subject of new generation of treatment.

Lee et al (2015)[79] studied to evaluate and compare the frictional resistance in self ligating brackets of different archwires, bracket materials, at different bracket-archwire angles. Both static and kinetic friction was measured. It was found that rectangular wires had high frictional values than the round wires. The passive self ligating metal brackets had the lowest static friction when compared with the active self ligating metal and active ceramic self ligating brackets.Both the static and dynamic friction increased as the bracket to archwire angulation increased.

Venugopal et al (2017)[80] reported that the microbial colonization around dental implants may lead to implant becoming loose or lost. The study concluded that titanium implants modified with Ti - BP - Silver nanoparticles exhibited excellent antibacterial properties thus upgrading to a better biomaterial .

Noronha anel Duran (2017)[81] reported that silver nanoparticles have great potential of being applicable in dentistry. These are promising systems which characterizes special features such as antimicrobial, antitumor, anti inflammatory and a potent carrier in drug delivery system. Silver nanoparticles are incorporated into nano composites, implant coatings, anti caries, local anesthetics. Their use is extensive in the field of dentistry.

Ghasemi et al (2017)[82] studied the effect of coating nanosilver and nanotitanium oxide films over brackets so as to decrease bacterial colonization and coefficient of friction stainless steel brackets were used for the study in direct contact with streptococcus mutans and bacterial load was found to be reduced. Nano titanium films were not helpful in decreasing friction.

Bergamo et al (2017)[83] evaluated the salivary level of bacterial species and in insitu. And also the design of brackets played an important factor as to whether it influenzed the risk of periodontal disease to develop or not. Bracket design should be considered in orthodontic treatment as different types of brackets influenced the bacteial adherence and colonization of white spot lesions as well as periodontal diseases for patients undergoing orthodontic therapy.

Gilani et al (2017)[84] studied the antibacterial and anti adherent properties of silver dioxide photocatalytic coatings on stainless steel brackets. It was proved that the coated brackets had bactericidal effects on streptococcus mutans. This innovation would be helpful in the prevention of formation of biofilms.

MATERIALS & METHODS

This study has been initiated in the department of orthodontics and dentofacial orthopedics, Sree Mookambika Institute of Dental Sciences, Kulasekharam, Tamilnadu in conjunction with Centre for NanoScience and Nanotechnology, Sathyabama University, Chennai and Sree ChithraThirunal Institute For Medical Sciences and Technology, Thiruvananthapuram, Kerala.

MATERIALS USED:

1. **Brackets**:

0.022 x 0.028 inch passive self-ligating stainless steel brackets of MBT prescription – SMART CLIP™ (3 M Unitek Orthodontic Products, USA) (Figure 1)

Upper right lateral incisor (Tip - 8º; Torque - 10°)	- 32nos
Canine(Tip - 8º; Torque - 0º)	- 32nos
First premolar brackets (Tip – 0°; Torque -7°)	-32 nos
	-Total 96 nos

2. **Archwires:**

Eight types of archwires of straight length were used for the study (Figure 2):

a. 0.017 x 0.025 inch rectangular stainless steel uncoated archwires. (Ormco Corp, Mexico) – 4 nos
b. 0.017 x 0.025 inch rectangular stainless steel silver nanoparticles coated archwires– 4 nos
c. 0.019 x 0.025 inch rectangular stainless steel uncoated archwires.(Ormco Corp, Mexico) – 4 nos
d. 0.019 x 0.025 inch rectangular stainless steel silver nanoparticles coated archwires. - 4 nos

e. 0.017 x 0.025 inch rectangular beta titanium uncoated archwires. (Ormco Corp, Glendora) - 4 nos

f. 0.017 x 0.025 inch rectangular beta titanium silver nanoparticles coated archwires. - 4 nos

g. 0.019 x 0.025 inch rectangular beta Titanium uncoated archwires. (Ormco Corp, Glendora) - 4 nos

h. 0.019 x 0.025 inch rectangular beta titanium silver nanoparticles coated archwires. - 4 nos

3. **70 % isopropyl alcohol**. (Wockhardt, Mumbai)(Figure 1)

4. **Marking Pen** (Faber –Castell) (Figure 1)

5. **An epoxy adhesive (**Araldite,Stafford,UK) (Figure 1)

6. **Measuring Scale** (Faber Castell) (Figure 1)

7. **Bracket Holding Tweezers** (Figure 1)

8. **Archwire Cutter (**SKODY**)** (Figure 1)

9. **Mathew Forceps**(CAT) (Figure 1)

10. **Poly Vinyl Acrylic clear sheet** of 8 mm thickness used for Jig fabrication. (Figure 1)

11. **Positioning Jig -** fabricated using 0.021 x0.025 inch stainless steel wire. (Figure 3)

12. **Elastomeric Modules** - Grey coloured elastomeric modules (GAC- Dentsply, USA) was used for positioning the bracket in the Jig while the Adhesive hardened. (Figure 1)

13..Dapen dish (Figure 1)

14. Swabs (Hicks, UP) (Figure 1)

15. Silver target material (GTR Manufacturer**)** (Figure 5)

16. Disengaging tool (3M,unitek,orthodontic products, USA) (Figure 15)

Equipment used:

1. Instron machine (Model no: 3345) (Instron corp, Canton , Massachussets ,USA)
2. DC Magnetron sputtering system (M/s Plassys, Magnetron sputtering System, Model MP300, France)
3. Gold sputter coater (E-1010, Ion sputter, Hitachi,Japan)
4. Scanning electron microscope (S-2400,Hitachi,JAPAN)
5. Profilometer(DEKTAK6M –Stylus Profiler, Veeco, USA)

INCLUSION CRITERIA:

(i) 0.019 x 0.025 & 0.017x0.025 inch rectangular- silver nanoparticle coated stainless steel orthodontic archwires.

(ii) 0.019 x 0.025 & 0.017x0.025 inch rectangular- silver nanoparticle coated beta titanium orthodontic archwires.

(iii) 0.019 x 0.025 & 0.017x0.025 inch rectangular - uncoated stainless steel orthodontic archwires.

(iv) 0.019 x 0.025 & 0.017x0.025 inch rectangular - uncoated beta titanium orthodontic archwires.

(v) Uncoated passive stainless steel self ligating brackets.

EXCLUSION CRITERIA:(i) Damaged archwires & brackets

CONSTITUTION OF THE TEST GROUPS OF ARCHWIRES

Total sample size of the study: 32 archwires

Number of groups to be studied: Two main groups,eight subgroups and eight subtypes.

Sample size of each group: 16 archwires.

Detailed description of the groups:

1. Group I – Stainless steel

a) Group IA (19SSC)	-	Stainless steel wires coated with AgNP
	-	0.019 x 0.025 inch
	-	Straight length
b) Group IB (19SSUC)	-	Stainless steel wires uncoated
	-	0.019 x 0.025 inch
(Ormco – Glendora, CA)	-	Straight length
c) Group IC (17SSC)	-	Stainless steel wires coated with AgNP
	-	0.017 x 0.025 inch,
	-	Straight length
d) Group ID (17SSUC)	-	Stainless steel uncoated wires
	-	0.017 x 0.025 inch
(Ormco corp – Glendora, CA)	-	Straight length

2. Group II – Beta titanium

a) Group IIA (19BC)	-	Beta titanium wires coated with AgNP
	-	0.019 x 0.025 inch
	-	Straight length

b) **Group IIB (19BUC)**
- Beta titanium uncoated wires
- 0.019x 0.025 inch.
- Straight length

(Ormcocorp, Glendora, CA)

c) **Group IIC (17BC)**
- Beta titanium wires coated with AgNp
- 0.017 x 0.025 inch
- Straight length

d) **Group II D (17BUC)**
- Beta titanium wires uncoated
- 0.017 x 0.025 inch
- Straight length

(Ormcocorp, Glendora, CA)

METHODOLOGY

A. PHYSICAL VAPOR DEPOSITION – DC MAGNETRON SPUTERRING

In this study, sixteen samples (Eight stainless steel of 19x25 inch – 4 each 17 x 25 inch - 4 each and eight beta titanium of 19x25 inch – 4 each , 17x25 inch – 4 each) were coated with silver nanoparticles of ~ 700 nm thickness at 200°C. In this study physical vapor deposition – Dc magnetron sputtering method(M/s Plassys, Magnetron sputtering System, Model MP300, France) (figure 6)is used for the deposition of AgNP on archwires.[18]

Thin film of silver nanoparticles was deposited by Dc - Magnetron sputtering system. It consisted of a stainless steel chamber of 45 cm diameter and 20 cm deep. A target disc of 76mm diameter was used. The deposition chamber had been evacuated to a base pressure of 8 x 10^{-4} Pa, making use of a pumping system comprising of a rotary and turbo molecular pumps (France). The operating pressure was 7.5 x 10^{-1} Pa.and the flow rate of Ar (99.99% purity) was set at 24 sccm. The direct current power was 15 watt with no duty cycle being set. The substrate temperature was set at 200°C or 573K. The argon flow rate was set using MKS make mass flow controller during sputtering ARPG – 50 as symmetric bipolar direct current power supply (MKS instruments , USA) has been used as the source of power supply for depositing thin film.

TARGET MOUNTING:

SILVER (Purity 99.99%) was used for the present study silver was obtained from the GTR manufacturer. Silver was used as the target and the target is the cathode. It was mounted on the disc vertically upward in the chamber. The target was mechanically mounted to a cathode assembly using a conducting silver paste.

The substrate – archwires to be coated, was placed vertically downwards in the present study. After the target was mounted, the continuity between the target and the base plate with the substrate was checked. As there should not be any shorting between the two. Throughout the experiment the distance between the target and the substrate was kept at 70mm. The target was clamped properly. (Figure-7)

SUBSTRATE PREPARATION AND SUBSTRATE HEATING

The substrate used were 7cm length stainless steel arch wires of dimensions 0.019inch (0.0483cm) x 0.025inch (0.063cm) and 0.017inch (0.0432 cm) x 0.025inch (0.063cm) (Figure-8). The second set consisted of 7cm length , beta titanium arch wires of dimension 0.019inch (0.0483cm) x 0.025inch (0.063cm) and 0.017 inch (0.0432cm) x 0.025inch (0.063cm)(Figure-9). The substrates were subjected to ultrasonic wave bath, the sonification process. The dust particles were removed and then degreased with acetone and dried in the hot air, in order to remove excess acetone, as water or any other liquid will contaminate the vaccum used in the chamber. Any contamination is to be avoided.

The substrate acts as the anode. The substrates were placed at regular intervals in the base plate substrate holder. Each group of the substrate to be coated was labelled accordingly and coating to be carried out in group wise manner. The substrate at both ends was fixed to the base plate substrate holder using kaptone tape(figure-10) , capable of withstanding temperature up to 300°C . A silicon wafer strip of 0.5mm thickness could be placed in single direction along with the substrates to check the thickness of the coating procedure.(Figure-11)

The chamber was fully closed and throttle valve fully opened and chamber was filled with vacuum and argon flow rate of 24 standard cubic cm per minute was maintained. The direct current mode supply was put on and power was increased. The target was sputtered for 10 minutes before the deposition, with the shuttle in closed condition at room temperature.This helps to remove any contamination present on the surface of the target. The substrate was heated at a temperature of 200°C.

THIN FILM DEPOSITION:

Silver nanoparticles thin films were deposited by sputtering in the argon atmosphere onto the substrates mounted on the base plate substrate holder, stainless steel archwires(Figure-12) and beta titanium archwires (Figures-13)

The evacuation of the deposition chamber was done at a base pressure of 8 x 10^{-4} Pa and working pressure was kept constant in order get an equal distribution of the nanometric layer without any disruption in the solid film surface of the substrate.

SHUT DOWN PROCEDURE:

The direct current power was switched off. The gas valve and Mass flow meter were switched off, waited till the substrate reached the room temperature. The rotary pump was switched off and the vent was opened till the chamber reached the atmospheric pressure. Gloves were worn during the loading and the unloading of the substrate and the target.

EXPERIMENTAL PARAMETERS FOR DEPOSITINGTHIN FILM OF SILVER NANOPARTICLES.

Base pressure	**$8x10^{-4}$Pa**
Operating pressure	**$7.5x10^{-1}$pa**
Substrate temperature	**200^{o}c or 573k**
Argon flow rate	**24Sccm**
Substrate to target distance	**70mm**
Dc Power	**15watt**

B. THICKNESS MEASUREMENT:

After the thin film deposition using DC Magnetron sputtering technique in this study, the film thickness was measured making use of profilometer (DEKTAK6M –Stylus Profiler ,USA) (Figure-14) . To measure the thickness, a step was created and the tip of the stylus was moved on the surface across the step. The size of the step was determined by measuring the difference between height of the coated and uncoated regions of the sample. It was noted to have thickness of ~700nm .

C. FRICTION TESTING:

For the present study, totally 96 passive metallic self-ligating brackets (smart clip^{TM} 3MUnitek, USA) of 0.022 x 0.028 inch stainless steel were cleansed using 70% isopropyl alcohol to remove any impurities from the bracket surface. The archwires uncoated – stainless steel and beta titanium were also cleansed using isopropyl alcohol.

JIG FABRICATION:

The jig to be mounted on the Instron universal testing machine (model 3345) (Instroncorp, Canton, Massachussets ,USA)was fabricated using clear perspex sheet of thickness - 8mm, length - 5cm and width - 8mm.

Doshi et al advocated the use of clean perspex sheet. Each sheet was marked in the midline, a line drawn parallel to the long axis of the sheet. It acted as a guide to ensure correctpositioning of the brackets that was to be bound. The perspex sheet was cut into precise dimensions using laser. Totally 32 blocks were fabricated.

The positioning of brackets on to the jig was done using a 0.021 x 0.025" SS wire. The brackets were bonded onto the perspex sheet using epoxy adhesive (Araldite, Stafford, UK). Jig was held in position, the brackets were placed in the order of lateral incisor, canine, first premolar and for standardization elastomeric modules were placed on the bracket – archwire combinations until the adhesive hardened so as to ensure not to damage the placed brackets, after which it was removed along with the 0.021 x 0.025"SS wire. The brackets were placed at regular interval of 5 mm to ensure uniform inter bracket width throughout the procedure(Figure 4).For each test, a new bracket-archwire combination was used The archwire was disengaged from the bracket using the tool (Figure15) .A length of 5cm of the arch wire was taken for the test from each group.

The archwire was securely placed onto the passive self -ligating brackets with the tool. The bracket archwire assembly was then mounted and positioned vertically in the Instron floor mounted machine(Figure-16).

The archwire protruding from the brackets on one end was carefully secured and held onto the upper jaws of the moveable crosshead, while the perspex sheet was held onto the lower arm. It was taken care that, the wire was parallel to the line which was marked onto the sheet. The archwire – bracket assembly was subjected to friction testing at a crosshead speed of 10mm / min , tested with a 100N load cell .The arch wire was pulled through the bracket at 10mm / min (Figure-17). After each test , a new assembly was mounted onto the machine for the next test as advocated by Tecco et al .[79]The plumbline present on the testing machine helped in ensuring that during the vertical pulling force of the machine at a crosshead speed of 10mm / min , the archwire and the bracket was also made parallel to the same, so that no twisting of the wire within the archwire –bracket assembly took place during the testing procedure .The test was carried out in dry state at room temperature .The load was calibrated from 0 to 100Nand the levels were transmitted to a computer (Figure-18).

D. SCANNING ELECTRON MICROSCOPE:

For studying the characteristic of silver nanoparticle coated stainless steel and beta titanium orthodontic archwires in their cross section, one sample of coated wire was taken from each group. The sample length was 7mm. These samples were also compared with the uncoated archwire samples of the same groups respectively. The samples were attached to a special holder which were sputter coated with gold in sputter coater (E-1010, Ion sputter, Hitachi,Japan) (Figure-19) . The samples consisted of uncoated, coated pretested, coated post tested in each set.(Figure-20) Each sample sets along with the holder were mounted on the scanning electron microscope (S-2400,Hitachi,JAPAN) (Figure-21,22).

These samples were then examined using magnification of X 3000 Measurements were taken to analyze the coating thickness and to evaluate the surface roughness of the coated wires before and after the friction test. It was marked using Zeiss software and photographs were taken and interpretation were made according to each group.

E. STATISTICAL ANALYSIS:

The data obtained by the mechanical testing was analyzed by using SPSS 16.0 version, (Microsoft Excel, Windows 7)Anova (Post hoc) followed by Shieffe's test and Unpaired t Test applied to find statistical significance between the groups. P values less than 0.05 considered statistically significant at 95% confidence interval.

FIGURES

Fig 1 - Armamentarium used

Fig 2 - Archwires

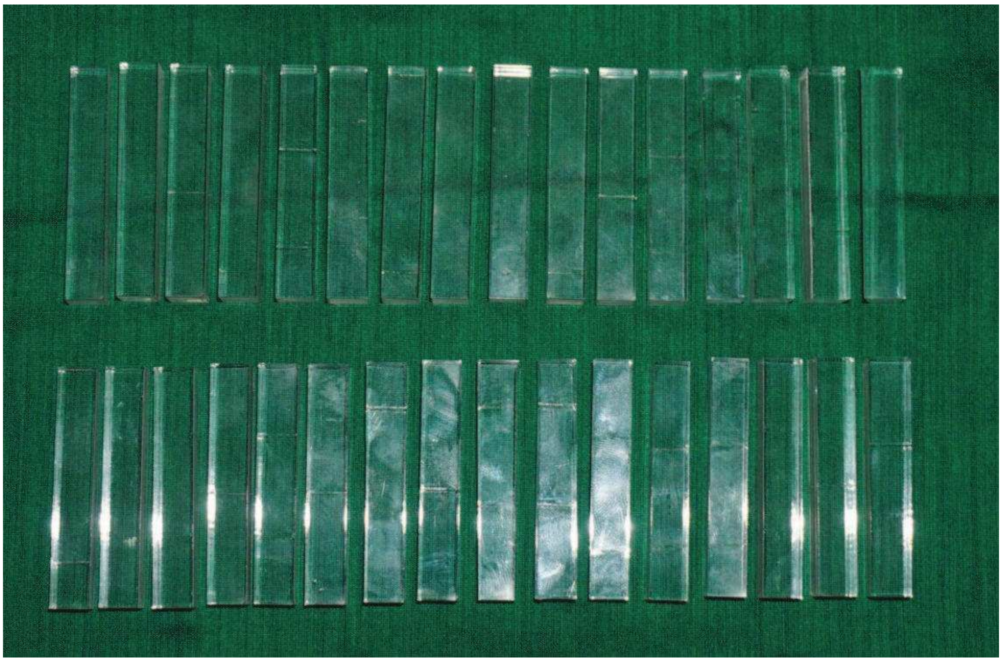


Fig 3 - Jigs

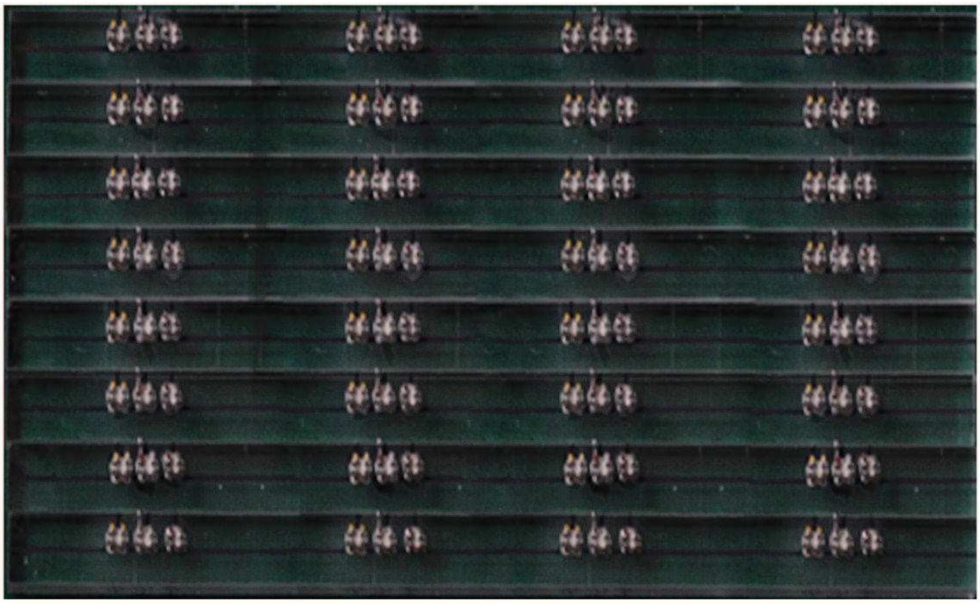


Fig 4 - Brackets mounted on Jig

Fig 5 - Silver - Target

Fig 6 - PVD Unit

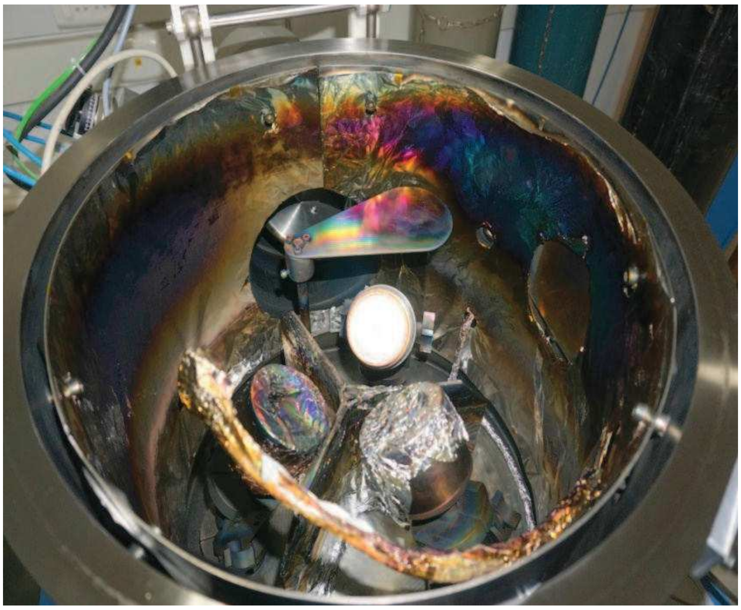


Fig 7 - Target holder

Fig 8 - Stainless steel archwires before coating on substrate holder

Fig 9 – Beta titanium archwires before coating on substrate holder

Fig 10- Kaptone tape

Fig 11- Silicon wafer strip mounted

Fig 12 – Stainless steel archwires after coating on substrate holder

Fig 13 - Beta titanium archwires after coating on substrate holder

Fig 14 - Stylus Profilometer

Fig 15 – Disengaging Tool

Fig 16 - Instron Machine

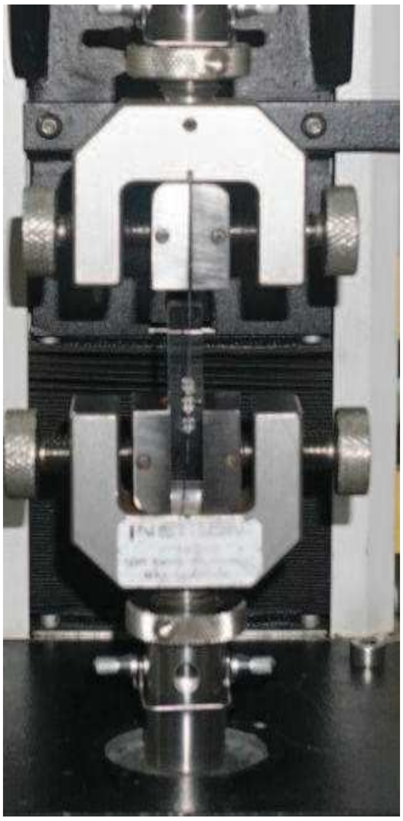


Fig 17 - Jig mounted on Instron

Fig 18 - Instron with software unit

Fig 19 - Gold sputter unit

Fig 20 - Discs before & after gold sputter

Fig 21 - Scanning electron Microscope unit

Fig 22- Discs mounted on Scanning electron microscope

RESULTS & OBSERVATIONS

The present study involved in the coating of rectangular stainless steel and beta titanium archwires with silver nanoparticles, through physical vapor deposition – Dc magnetron sputtering method, with an objective to find out whether silver nanoparticles (AgNP) coated archwires exhibited low frictional values during the mechanical testing .

The analysis was directed to compare the frictional values of silver nanoparticles coated stainless steel and beta titanium archwires with that of uncoated stainless steel and beta titanium archwires.

The values obtained in Newton (N) were:

Group IA (19 SSC)	-	1.62 ± 0.96 N
Group IB (19 SSUC)	-	1.23 ± 1.37 N
Group IC (17 SSC)	-	1.02 ±0.96 N
Group ID (17 SSUC)	-	0.92 ± 0.86 N
Group IIA (19 BC)	-	0.98 ± 0.92 N
Group II B (19 BUC)	-	3.50± 0.90 N
Group IIC (17 BC)	-	0.26 ± 0.36 N
Group II D (17 BUC)	-	2.20± 1.28 N

The least frictional force value is shown by Group II C – 17BC and the highest friction was shown by group II B -19BUC.

The Group II A shows less frictional value than group II B.

The Group – II C has shown to be of less frictional resistance than Group II A, when compared with each other. The Group II C has shown to be of less frictional resistances than Group – II D, when compared with each other.

According to the statistical analysis:

Table 1, shows the mean frictional force value of stainless steel groups at a cross head speed of 10mm/ min.

Table 1: Mean values of stain less steel groups

Groups	Materials	Load at Max (MEAN±SD)
Group-IA	19SSC	1.62±0.96
Group-IB	19SSUC	1.23±1.37
Group-IC	17SSC	1.02±0.96
Group-ID	17SSUC	0.92±0.86

Table 2, shows the mean frictional force values of beta titanium group at a cross

Table-2: Mean values of beta titanium groups

Groups	Materials	Load at Max (MEAN±SD)
Group-IIA	19BC	0.98±0.92
Group-IIB	19BUC	3.50±0.90
Group-IIC	17BC	0.26±0.36
Group-IID	17BUC	2.20±1.28

Table 3, compares the mean frictional values of Group - I A with Group - I B.

The statistical comparison shows no significant difference between the groups taken into account, the p value is more than 0.05.

Table 3 : Comparison of mean Load at Max values of Group-IA with Group-IB

Groups	Materials	Load at Max (MEAN±SD)	P value
Group-IA	19SSC	1.62±0.96	0.56
Group-IB	19SSUC	1.23±1.37	

(p>0.05 no significant difference compared Group-IA with Group-IB)

Table 4 , compares the mean frictional values of Group – I C with Group – I D

The statistical comparison shows no significant difference between the groups taken into account, the p value is more than 0.05.

Table 4: Comparison of mean Load at Max values of Group-IC with Group-ID

Groups	Materials	Load at Max (MEAN±SD)	P value
Group-IC	17SSC	1.02±0.96	0.67
Group-ID	17SSUC	0.92±0.86	

(p>0.05 no significant difference compared Group-IC with Group-ID)

Table 5, the test shows the multiple comparison of mean load at maximum values between the subgroups of Group I.

The statistical analysis shows no significance difference between the subgroups of Group I (* $P > 0.05$).

Table 5: Multiple comparison of mean Load at Max values between the subgroups of Group-I

Groups	Materials	Load at Max (MEAN±SD)
Group-IA	19SSC	1.62±0.96
Group-IB	19SSUC	1.23±1.37
Group-IC	17SSC	1.02±0.96
Group-ID	17SSUC	0.92±0.86

(p>0.05 no significant difference compared between the subgroups of Group-I)

Table 6, compares the mean frictional values between the Group - II A with Group - II B.

The statistical comparison shows significant value between the groups taken into account, p value is 0.04 less than 0.05 (*P<0.05).Group - II A is significantly lower in value than group - II B.

Table 6 : Comparison of mean Load at Max values between the Group-IIA with Group-IIB

Groups	Materials	Load at Max (MEAN±SD)	P value
Group-IIA	19BC	0.98±0.92	0.04
Group-IIB	19BUC	3.50±0.90*	

(*p<0.05 significant compared Group-IIA with Group-IIB)

Table 7**,** compares the mean frictional values between the Group – IIC with Group - II D

The statistical comparison shows significant value between the Groups taken into account, p value is 0.04 less than 0.05 (*P<0.05). Group - II C is significantly lower in value than group - II D.

Table 7: Comparison of mean Load at Max values between the Group-IIC with Group-IID

Groups	Materials	Load at Max (MEAN±SD)	P value
Group-IIC	17BC	0.26±0.36	0.04
Group-IID	17BUC	2.20±1.28*	

(*p<0.05 significant compared Group-IIC with Group-IID)

Table 8, the test shows the multiple comparison of mean load at Maximum values between the subgroups of Group II.

The statistical analysis shows statistical significant difference when Group II A was compared with other groups (*P<0.05) and when group – II B was compared with other Groups (* P<0.005) and Group II C was compared with other groups.

Table 8: Multiple comparison of mean load at Max values between the subgroups of Group-II

Groups	Materials	Load at Max (MEAN±SD)
Group-IIA	19BC	0.98±0.92
Group-IIB	19BUC	3.50±0.90
Group-IIC	17BC	0.26±0.36$^{*,\#}$
Group-IID	17BUC	2.20±1.28$^{\$}$

(*p<0.05 significant compared Group-IIA with other groups, $^{\#}$p<0.05 significant compared Group-IIB with other groups, $^{\$}$p<0.05 significant compared Group-IIC with other groups)

Table 9, compares the mean frictional values of Group IA with other groups.

The statistical comparison shows a statistical significant difference (*P < 0.05) with group II B and group II C.

Table 9: Comparison of mean load at Max values of Group-IA with other groups

Groups	Material	Load at Max (MEAN±SD)	p value
Group-IA	19SSC	1.62±0.96	
Group-IB	19SSUC	1.23±1.37	0.56
Group-IC	17SSC	1.02±0.96	0.45
Group-ID	17SSUC	0.92±0.86	0.89
Group-IIA	19BC	0.98±0.92	0.82
Group-IIB	19BUC	3.50±0.90*	0.04
Group-IIC	17BC	0.26±0.36*	0.03
Group-IID	17BUC	2.20±1.28	0.07

(*p<0.05 significant compared Group-IA with other groups)

Table 10, compares the mean frictional values of Group IB with other Groups.

The statistical comparison shows a statistical significant difference (*P <0.05) with group II B and group II C.

Table 10: Comparison of mean load at Max values of Group-IB with other groups

Groups	Material	Load at Max (MEAN±SD)	p value
Group-IA	19SSC	1.62±0.96	0.56
Group-IB	19SSUC	1.23±1.37	
Group-IC	17SSC	1.02±0.96	0.67
Group-ID	17SSUC	0.92±0.86	0.45
Group-IIA	19BC	0.98±0.92	0.48
Group-IIB	19BUC	3.50±0.90*	0.04
Group-IIC	17BC	0.26±0.36*	0.04
Group-IID	17BUC	2.20±1.28	0.06

(*p<0.05 significant compared Group-IB with other groups)

Table 11, compares the mean frictional values of Group – IC with other groups.

The statistical comparison shows a statistical significant difference (*P <0.05) with other groups - with group II B and group II C.

Table 11: Comparison of mean load at Max values of Group-IC with other groups

Groups	Material	Load at Max (MEAN±SD)	p value
Group-IA	19SSC	1.62±0.96	0.45
Group-IB	19SSUC	1.23±1.37	0.67
Group-IC	17SSC	1.02±0.96	
Group-ID	17SSUC	0.92±0.86	0.67
Group-IIA	19BC	0.98±0.92	0.87
Group-IIB	19BUC	3.50±0.90*	0.04
Group-IIC	17BC	0.26±0.36*	0.04
Group-IID	17BUC	2.20±1.28	0.08

(*p<0.05 significant compared Group-IC with other groups)

Table 12, compares the mean frictional values of Group – ID with other groups.

The statistical comparison shows a statistical significant difference (*P<0.05) with other groups - with group II B and group II C

Table 12: Comparison of mean load at Max values of Group-ID with other groups

Groups	Material	Load at Max (MEAN±SD)	p value
Group-IA	19SSC	1.62±0.96	0.89
Group-IB	19SSUC	1.23±1.37	0.45
Group-IC	17SSC	1.02±0.96	0.67
Group-ID	17SSUC	0.92±0.86	
Group-IIA	19BC	0.98±0.92	1.45
Group-IIB	19BUC	3.50±0.90*	0.03
Group-IIC	17BC	0.26±0.36	0.06
Group-IID	17BUC	2.20±1.28*	0.04

(*p<0.05 significant compared Group-ID with other groups)

Table 13, compares the mean frictional values of Group – II A with other groups.

The statistical comparison shows a statistical significant difference (*P<0.05) with other groups – group II B and group II D.

Table 13: **Comparison of mean load at Max values of Group-IIA with other groups**

Groups	Material	Load at Max (MEAN±SD)	p value
Group-IA	19SSC	1.62±0.96	0.82
Group-IB	19SSUC	1.23±1.37	0.48
Group-IC	17SSC	1.02±0.96	0.87
Group-ID	17SSUC	0.92±0.86	1.45
Group-IIA	19BC	0.98±0.92	
Group-IIB	19BUC	3.50±0.90*	0.03
Group-IIC	17BC	0.26±0.36	0.07
Group-IID	17BUC	2.20±1.28*	0.04

(*p<0.05 significant compared Group-IIA with other groups)

Table 14**,** compares the mean frictional values of Group – II B with other groups.

The statistical comparison shows a statistical significant difference (*P<0.05) with other groups – group II A and group II C.

Table 14: Comparison of mean load at Max values of Group-IIB with other groups

Groups	Material	Load at Max (MEAN±SD)	p value
Group-IA	19SSC	1.62±0.96	0.07
Group-IB	19SSUC	1.23±1.37	0.06
Group-IC	17SSC	1.02±0.96	0.08
Group-ID	17SSUC	0.92±0.86	1.45
Group-IIA	19BC	0.98±0.92*	0.04
Group-IIB	19BUC	3.50±0.90	
Group-IIC	17BC	0.26±0.36*	0.03
Group-IID	17BUC	2.20±1.28	0.08

(*p<0.05 significant compared Group-IIB with other groups)

Table 15, compares the mean frictional values of Group – II C with other groups.

The statistical comparison shows a statistical significant difference (*P<0.05) of group – II C with other groups – group I A , group I B, group I C, group II B, group II D.

Table 15: Comparison of mean load at Max values of Group-IIC with other groups

Groups	Material	Load at Max (MEAN±SD)	p value
Group-IA	19SSC	1.62±0.96*	0.03
Group-IB	19SSUC	1.23±1.37*	0.04
Group-IC	17SSC	1.02±0.96*	0.04
Group-ID	17SSUC	0.92±0.86	0.06
Group-IIA	19BC	0.98±0.92	0.07
Group-IIB	19BUC	3.50±0.90*	0.04
Group-IIC	17BC	0.26±0.36	
Group-IID	17BUC	2.20±1.28*	0.03

(*p<0.05 significant compared Group-IIC with other groups)

Table 16**,** compares the mean frictional values of Group – II D with other groups.

The statistical comparison shows a statistical significant difference (*P<0.05) of group – II D with other groups – group I A, group I B, group I C, group I D, group II A, group II C.

Table 16: Comparison of mean load at Max values of Group-IID with other groups

Groups	Material	Load at Max (MEAN±SD)	p value
Group-IA	19SSC	1.62±0.96*	0.04
Group-IB	19SSUC	1.23±1.37*	0.04
Group-IC	17SSC	1.02±0.96*	0.04
Group-ID	17SSUC	0.92±0.86*	0.03
Group-IIA	19BC	0.98±0.92*	0.03
Group-IIB	19BUC	3.50±0.90	0.08
Group-IIC	17BC	0.26±0.36*	0.04
Group-IID	17BUC	2.20±1.28	

(*p<0.05 significant compared Group-IID with other groups)

PROFILOMETRY:

The coating thickness is uniform and even, measuring upto ~700nm.

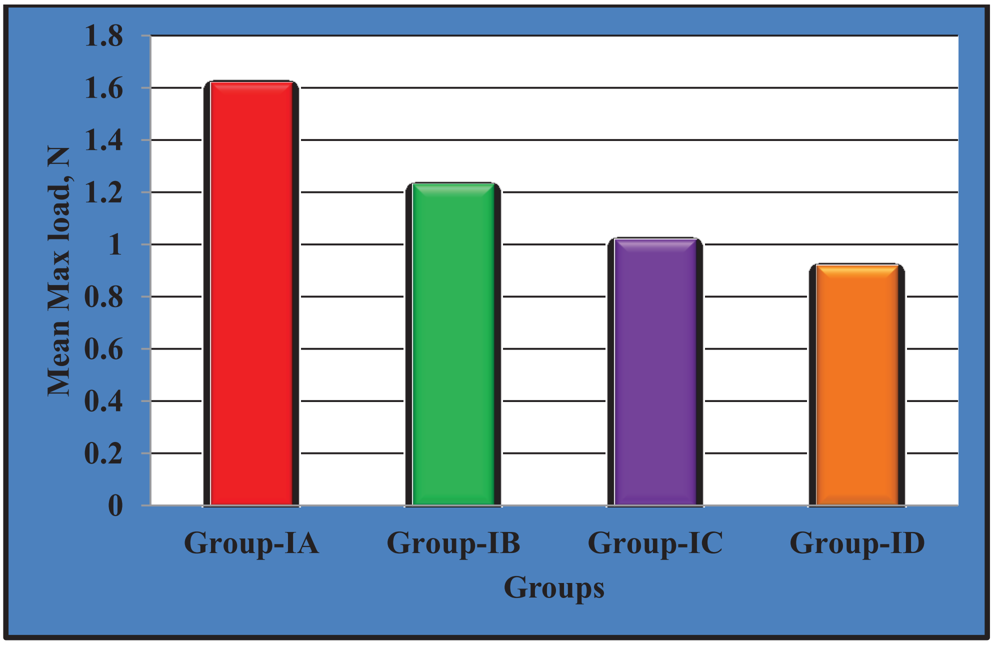
SCANNING ELECTRON MICROSCOPY

At a Magnification of 3000x, width of 10mm there is no significant difference between the pretested and post tested AgNP coated samples of beta titanium archwires, the control uncoated sample of both 0.017 x 0.025 inch and 0.019 x 0.025 inch beta titanium archwires shows significant surface irregularities owing to the subjection of high friction during the friction testing.

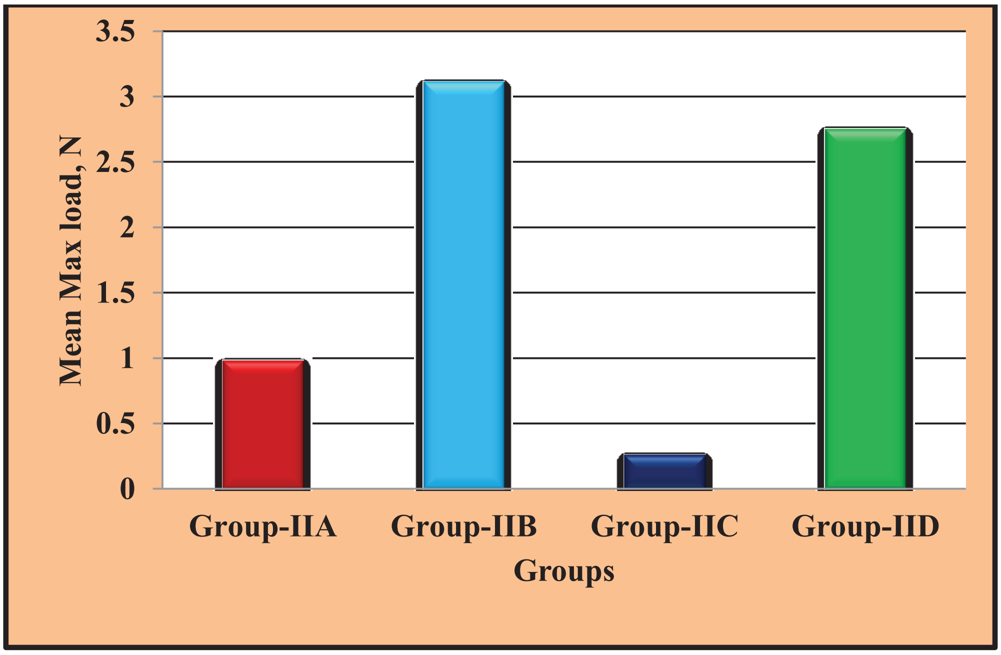
The AgNP coated stainless steel archwires shows no significant surface alterations in the post tested samples, apart from minor vertical lines and irregularities in the post tested samples.0.017 x 0.025 inch stainless steel shows debris adherence in the post tested AgNP coated sample, probably the adherence of fibres of cotton used to clean the sample prior to testing. The control uncoated stainless steel samples shows no significant difference in the surface characteristic after the friction test. No peeling off the AgNP coated layer was observed in either test Group I or in Test Group II after the friction test.

GRAPHS

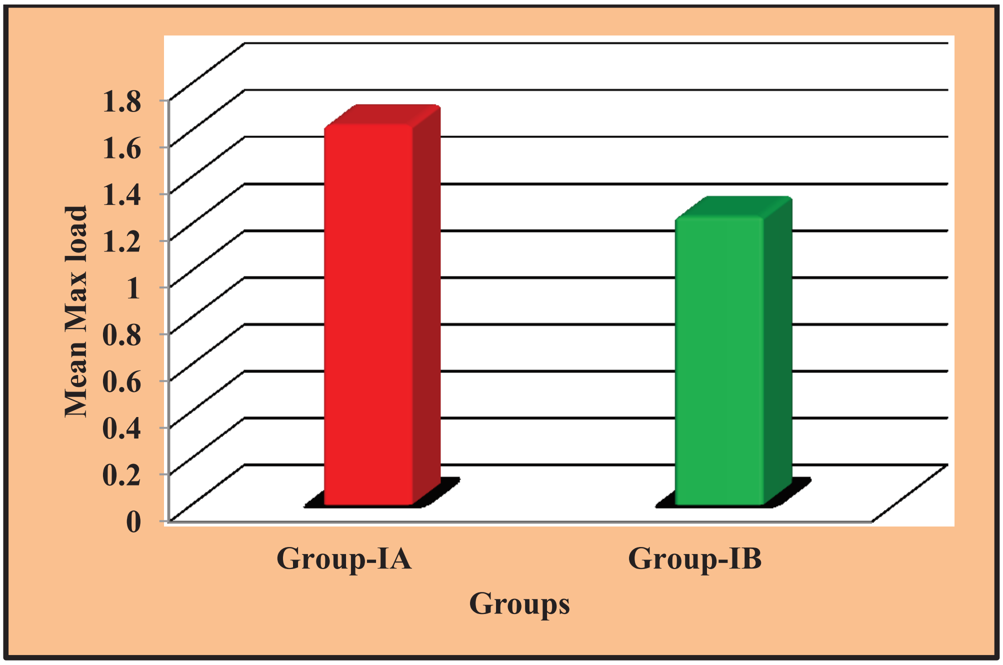
Graph-1: Mean values of stain less steel groups



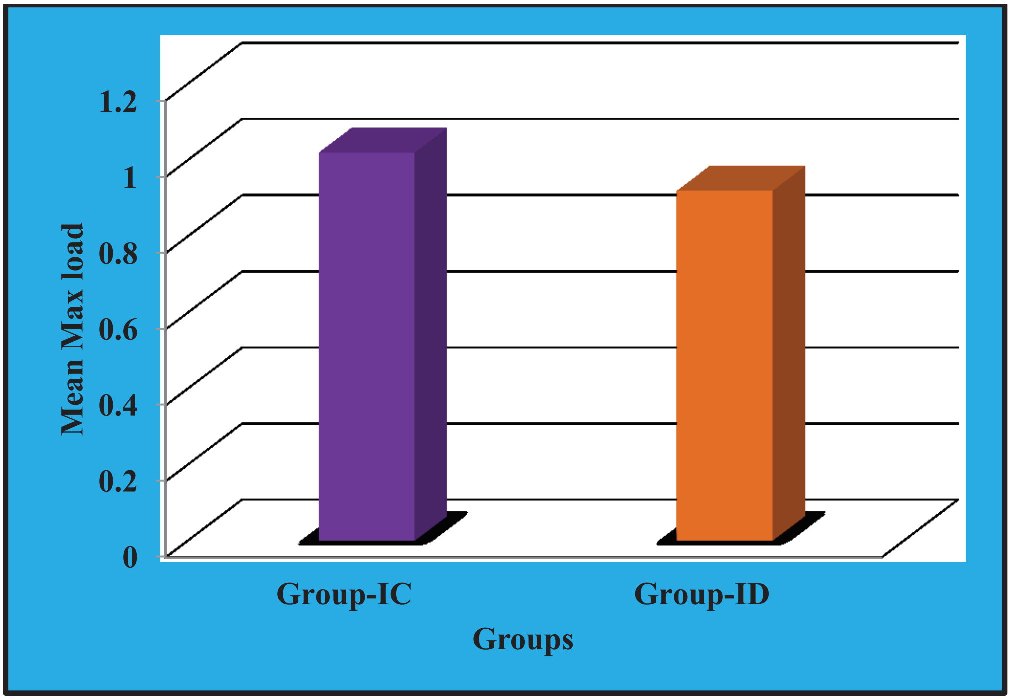
Graph-2: Mean values of beta titanium groups



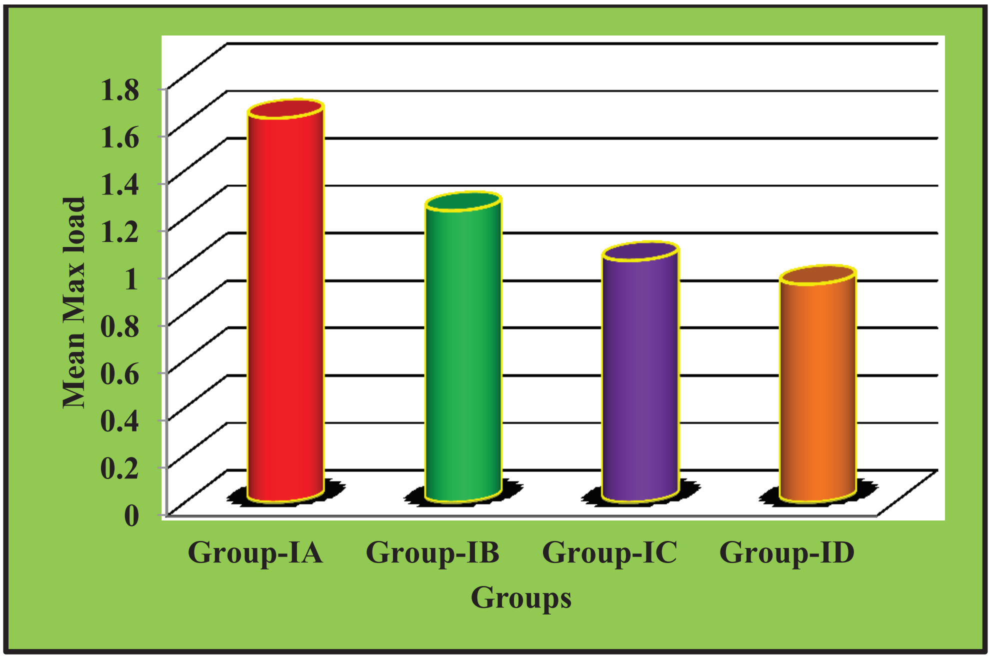
Graph-3: Comparison of mean Load at Max values of Group-IA with Group-IB



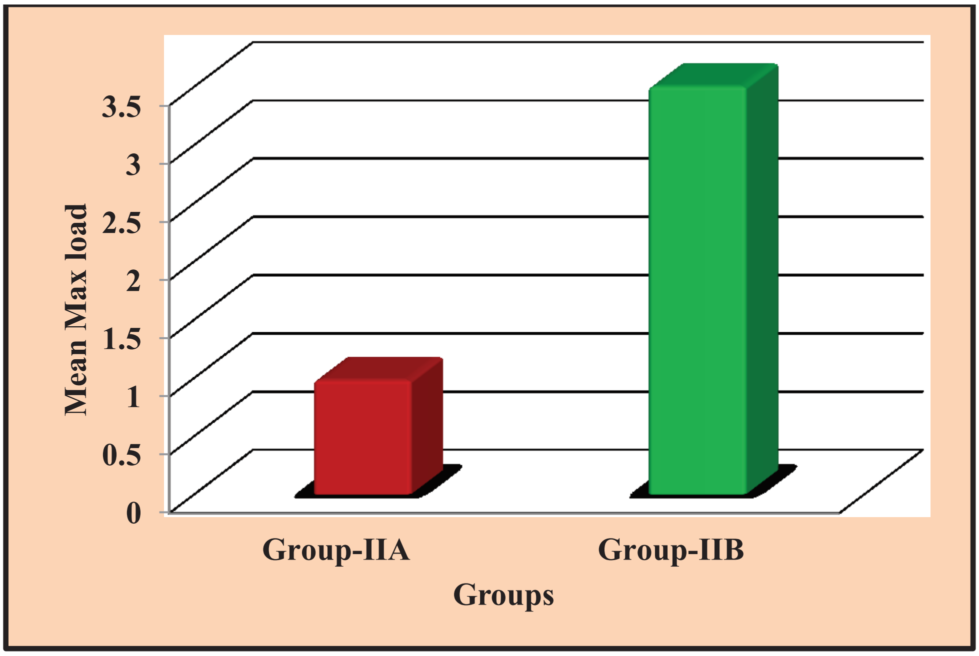
Graph-4: Comparison of mean Load at Max values of Group-IC with Group-ID



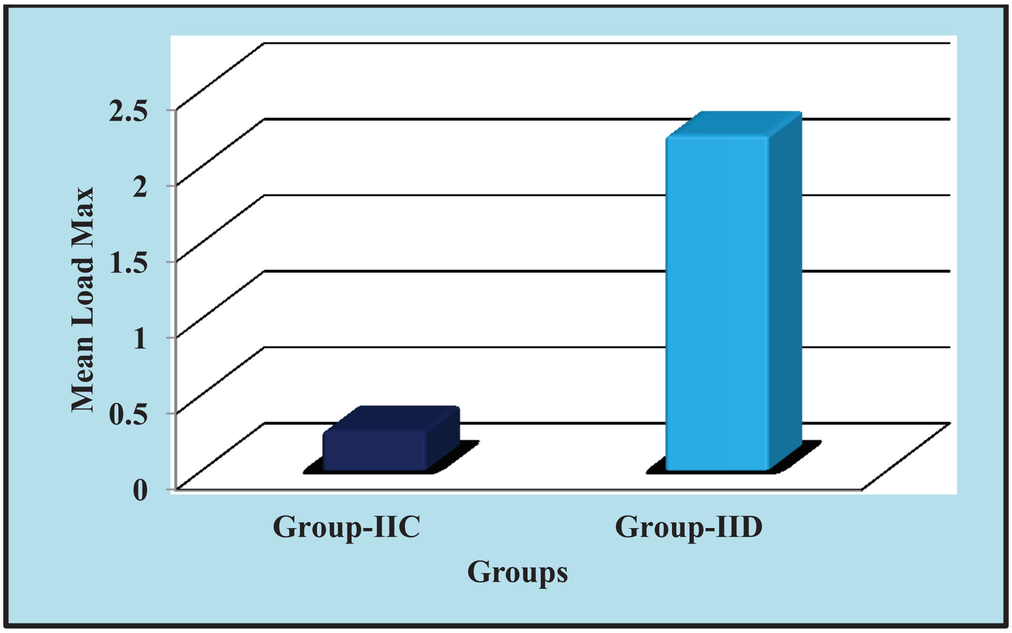
Graph-5: Multiple comparison of mean Load at Max values between the subgroups of Group-I



Graph-6: Comparison of mean Load at Max values between the Group-IIA with Group-IIB



Graph-7: Comparison of mean Load at Max values between the Group-IIC with Group-IID



Graph-8: Multiple comparison of mean load at Max values between the subgroups of Group-II

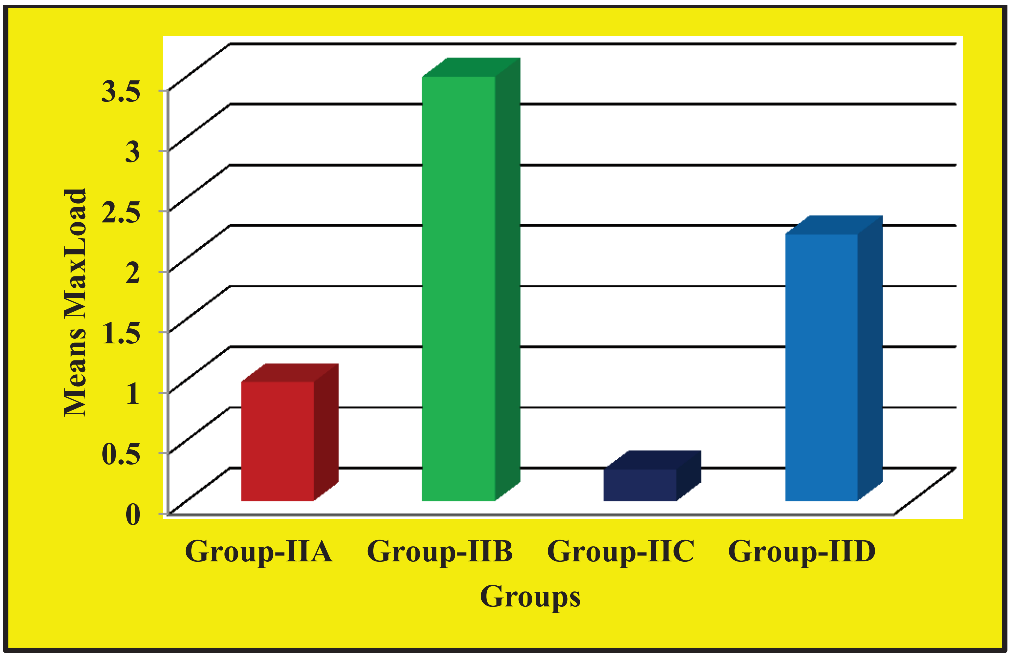
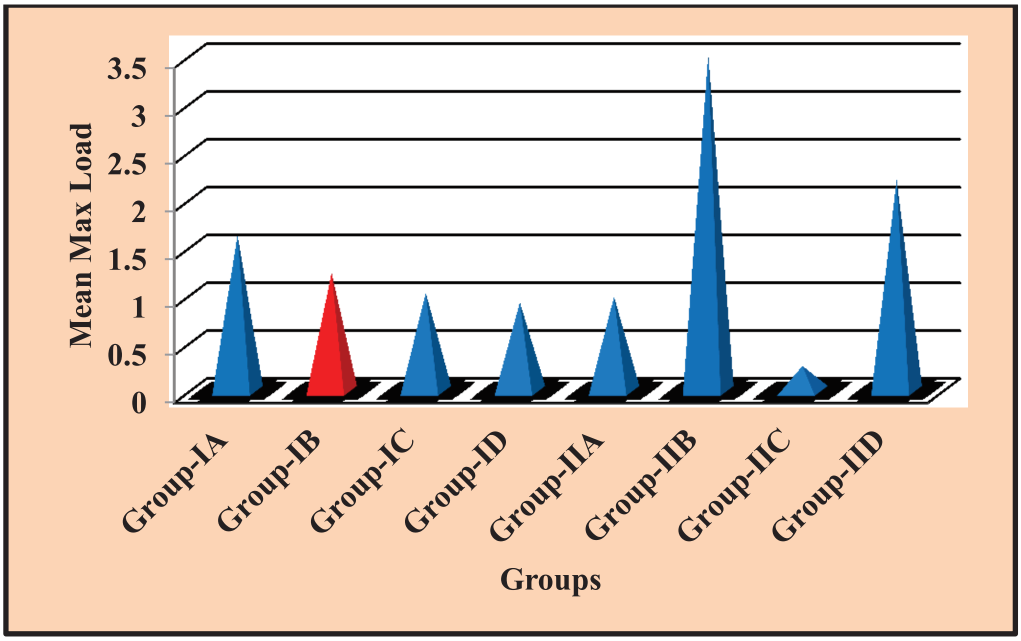
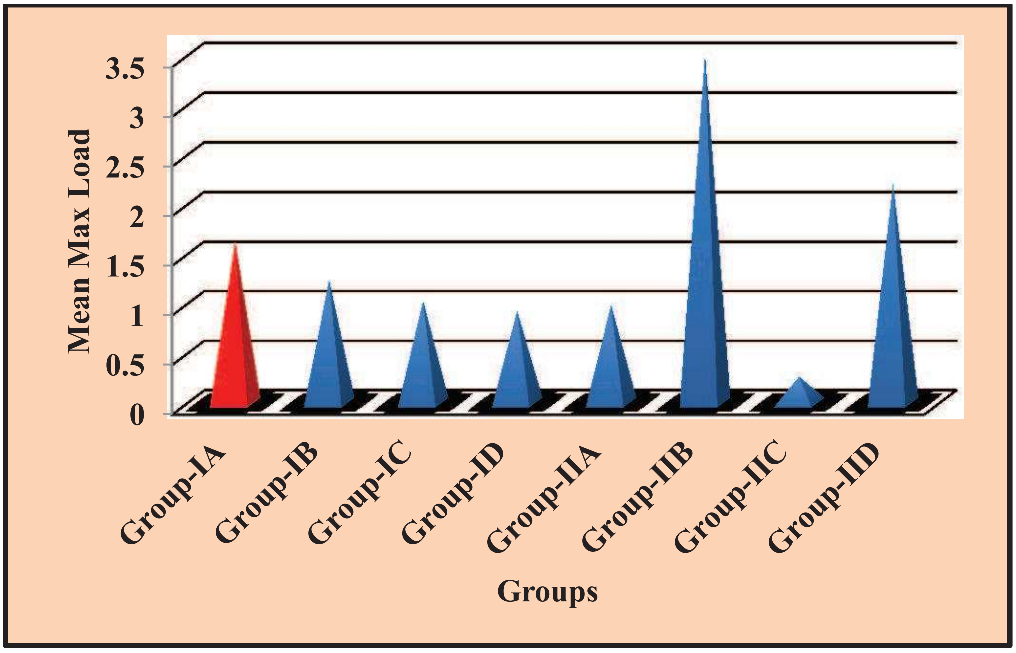


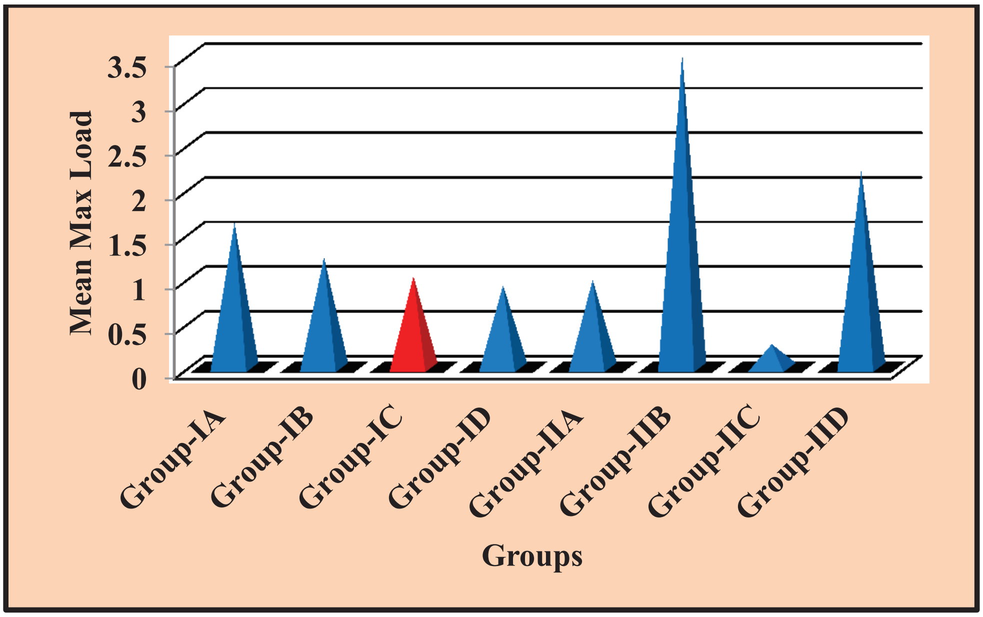
Table-9: Comparison of mean load at Max values of Group-IA with other groups



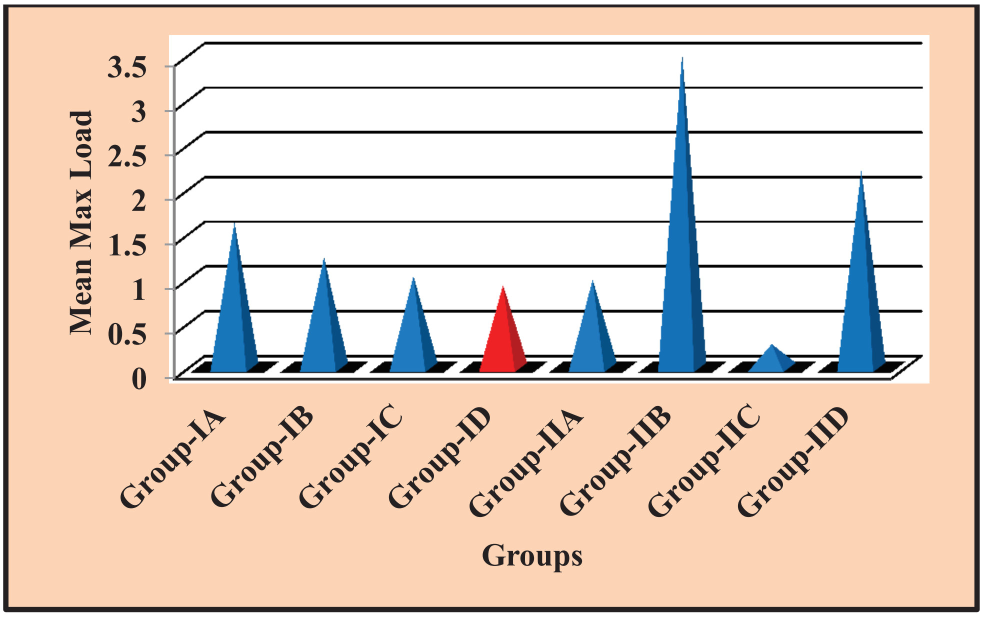
Graph-10: Comparison of mean load at Max values of Group-IB with other groups



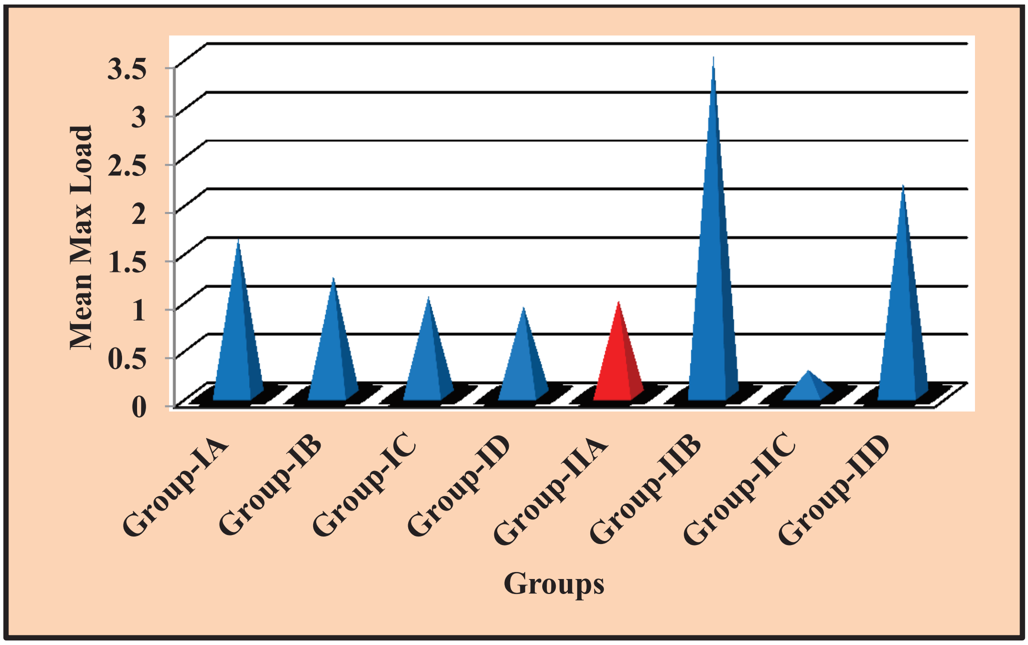
Graph-11: Comparison of mean load at Max values of Group-IC with other groups



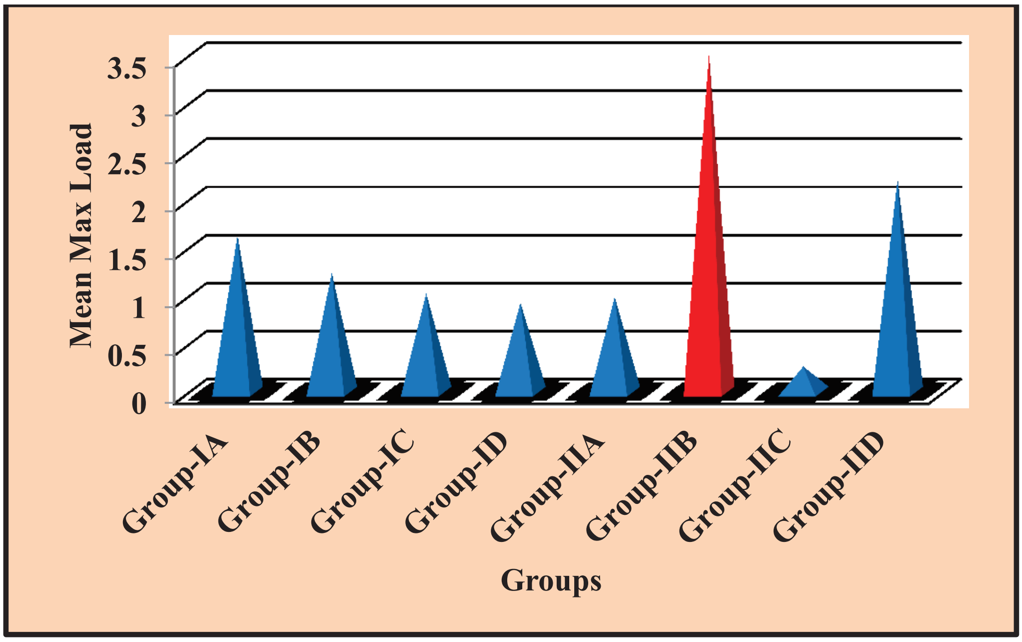
Graph-12: Comparison of mean load at Max values of Group-ID with other groups



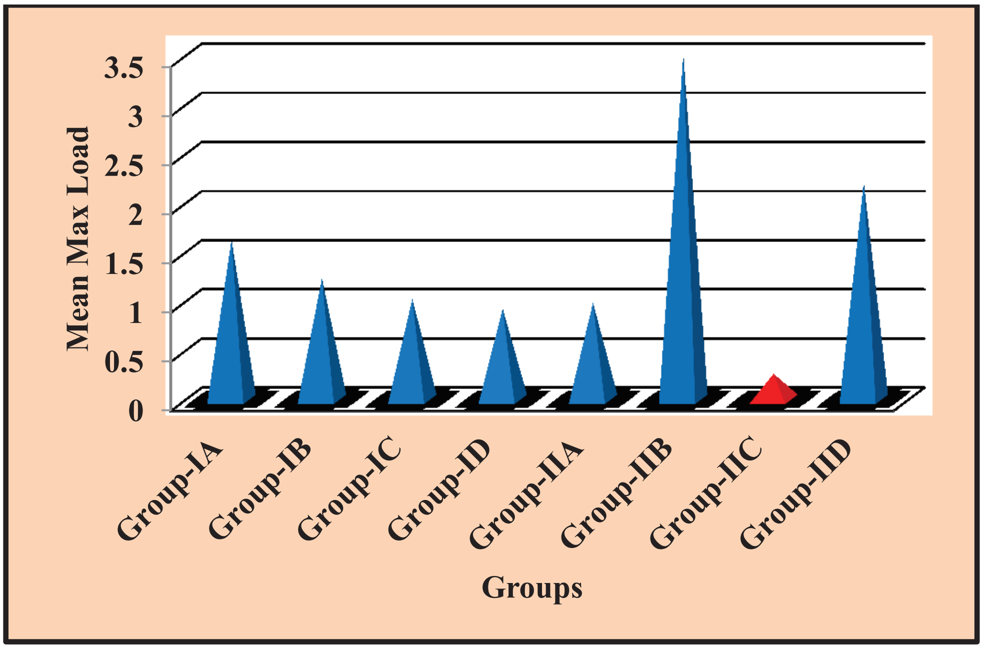
Graph-13: Comparison of mean load at Max values of Group-IIA with other groups



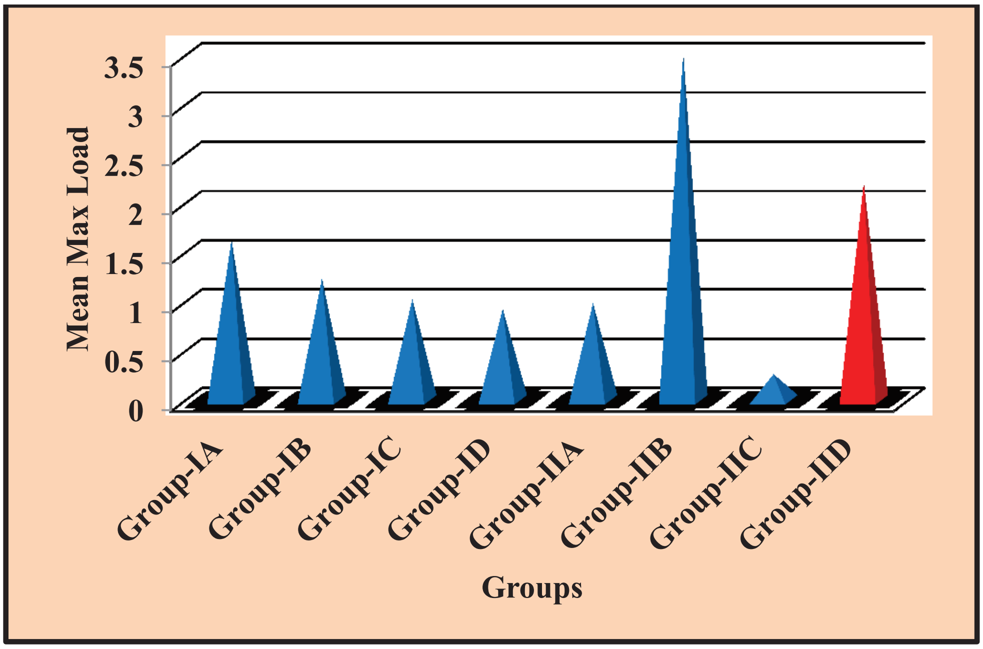
Graph-14: Comparison of mean load at Max values of Group-IIB with other groups



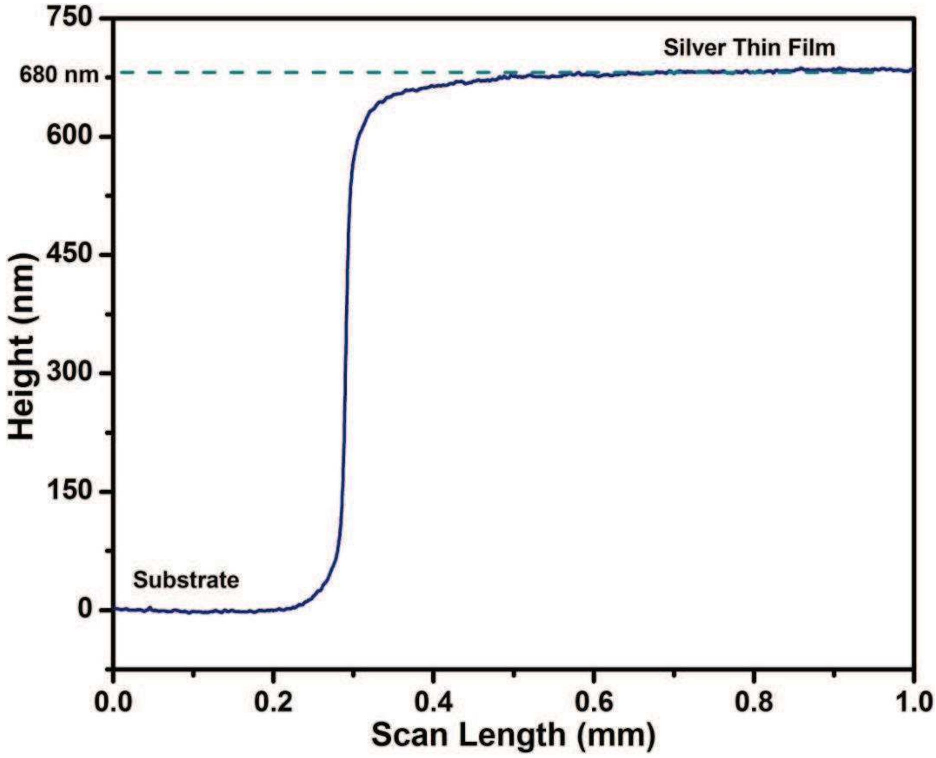
Graph-15: Comparison of mean load at Max values of Group-IIC with other groups



Graph-16: Comparison of mean load at Max values of Group-IID with other groups

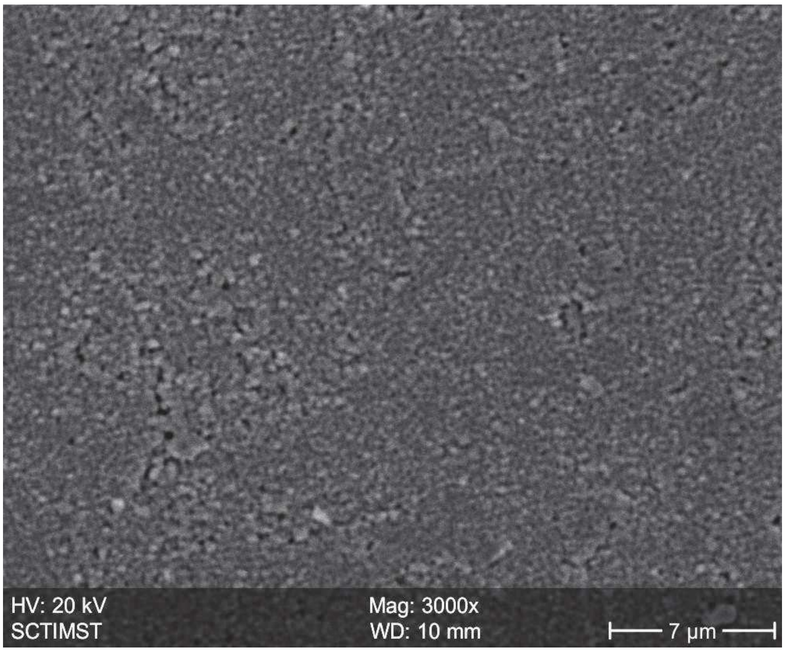


Graph 17 – Profilometry – Thickness

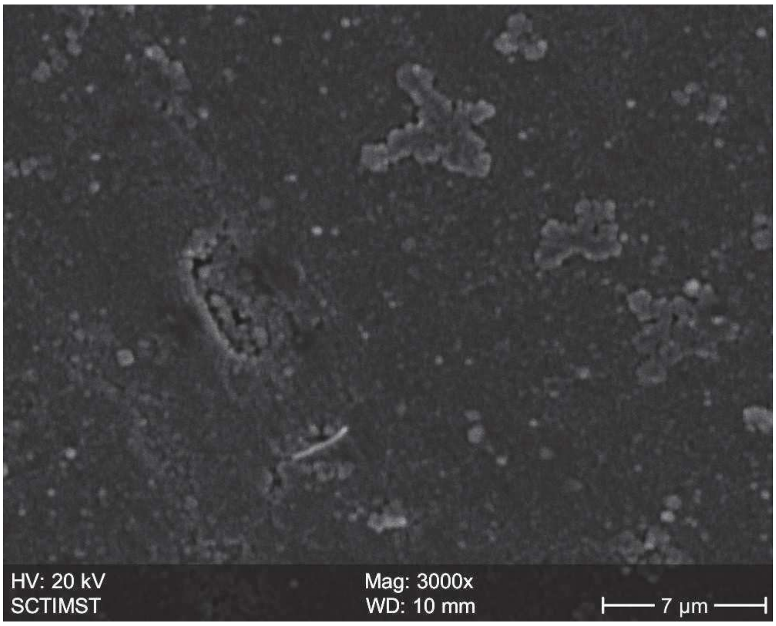


SEM RESULTS

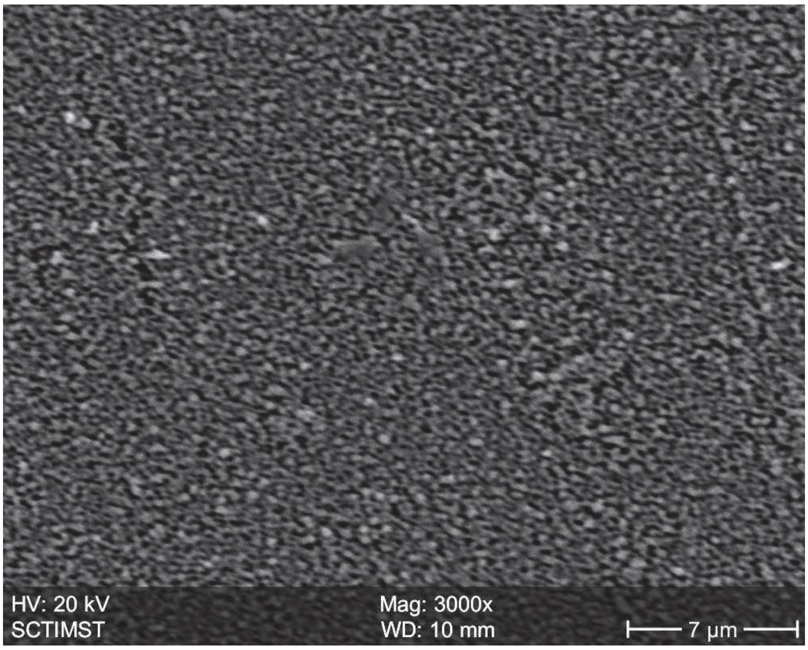
19 SSC – Coated (Before test)



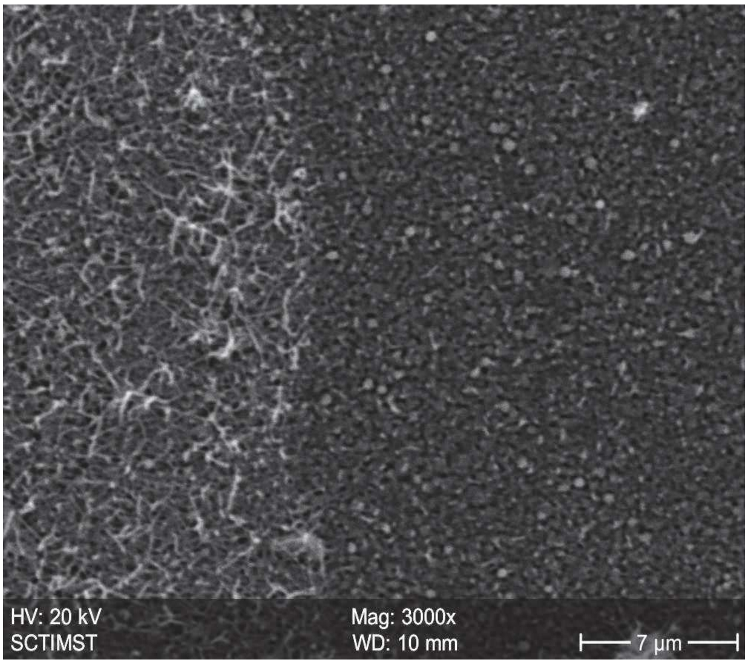
19SSC – Coated (After test)



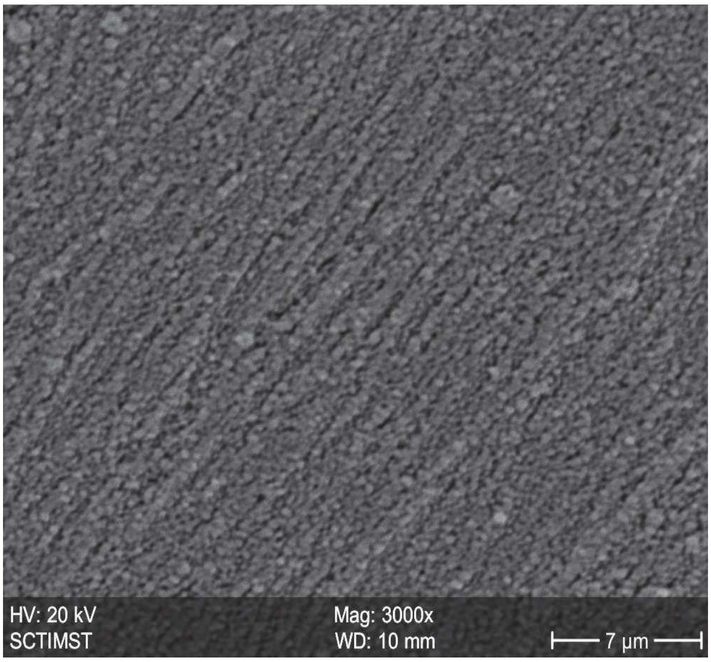
17SSC – Coated (Before test)



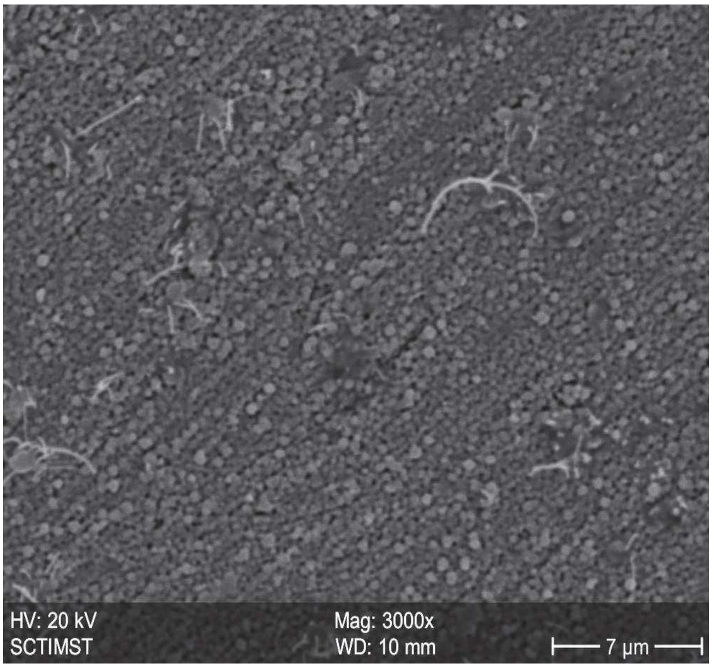
17SSC – Coated (After test)



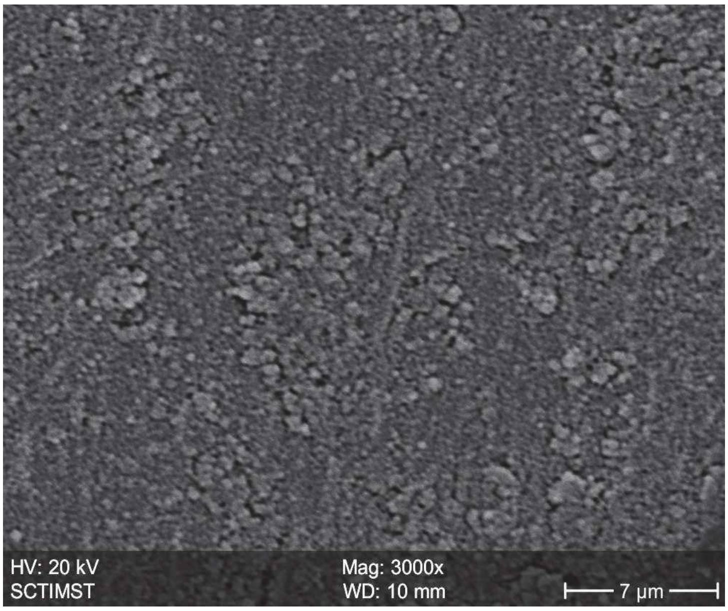
19 BC – Coated (Before test)



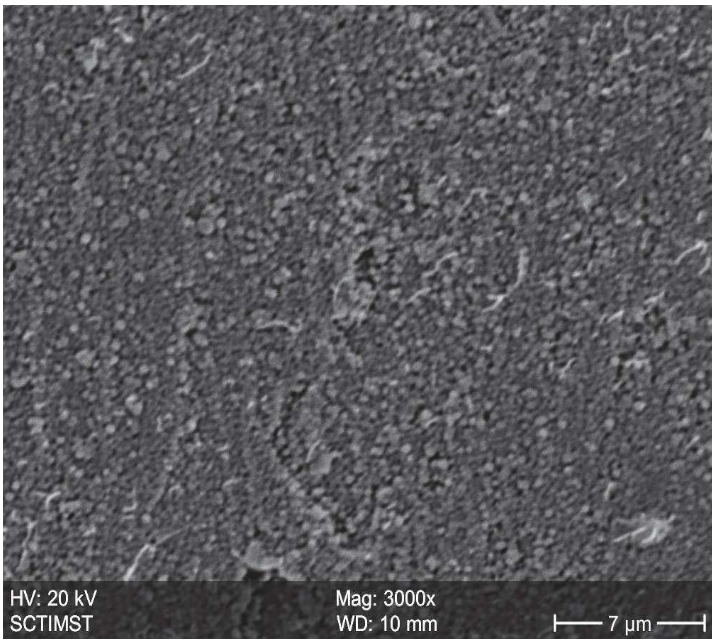
19BC – Coated (After test)



17BC –Coated (Before test)



17BC – Coated (After test)



DISCUSSION

The aim of the study was to evaluate the frictional values between two different orthodontic archwires namely, stainless steel and beta titanium coated with silver nanoparticles using passive self-ligating brackets. The study was designed also to improve and check the surface roughness of the coated archwires.

To assess the improvement in the frictional values of the archwires, it was subjected to friction test. From the present study two main groups, eight sub groups and eight sub types were studied for the assessment of the frictional values and evaluating the surface topography before and after friction testing.

Each archwire has it's unique mechanical, biological and surface characteristics. This may sometimes significantly vary due to the manufacturer's liabilility.[42]These archwires comes in different sizes, cross sections, mechanical properties, surface finishing . So the selection of the archwires is very important. For a desirable periodontal response the frictional forces must be overcome. Thus light continous forces are more favourable during the tooth movement providing comfortability to the patient and for preserving the anchorage.[26,30]

Advances in the bio engineering and bio materials field has provided solution for the creation of the archwires with low coefficient of friction.[45]Generally the archwire performance depends on the material cross section and surface roughness. Smaller archwires deliver lower forces than larger archwires that is generally used during the later stages of treatment.[69]The play in the bracket - archwire contributes to the values of friction that is generated during the treatment. Rectangular archwires offers less play than the round wires.[57]Depending on the treatment stage, appropriate archwires should be selected. Thus the choice and sequencing of the archwires should be made in a rational manner and according to the clinical care requirement and on the present scientific evidence.[25]

This study was carried out with the archwires of dimensions 0.017 x 0.025 inch, 0.019 x 0.025 inch stainless steel and 0.017 x 0.025 inch, 0.019 x 0.025 inch beta titanium .TMA was chosen for the study since it was found in previous studies, that the mechanical characteristics of the archwire improved after coating was done.[12]HerePVD coating of AgNP on both SS and TMA archwires was carried out. Kusy et al has stated the thermal and mechanical characteristics of stainless steel when subjected to comparison with beta titanium and nickel titanium alloys. When compared with Nitinol, TMA was smoother, could be welded, showed good formability and good corrosion resistance .On comparison with stainless steel, TMA produced higher springback, more range, gentle linear forces per unit of deactivation. It's drawback was it had greater frictional force values than stainless steel.[52]Other studies compared the sliding resistance of self-ligating stainless steel conventional stainless steel, titanium brackets, with stainless steel and TMA archwires. The self-ligating bracket with TMA archwires showed less resistance in friction compared with the other archwires. The titanium bracket with TMA archwires had less friction when compared to stainless steel brackets stated by Khalid et al.[65]

Usually in sliding mechanics 0.019 x 0.025 inch SS wire is used as the basic sliding wire due to its mechanical properties being a stiffer wire and having less friction when compared to beta titanium.The frictional force values usually increases for beta titanium with increased sliding.[46]In order to reduce the friction, coating was done on the archwires.0.017 x 0.25 inch and 0.019 x 0.025 inch beta titanium.

Stainless steel has relatively low spring back and produces high forces that dissipates over shorter duration of time, indicating the need of frequent changing of archwires , as stated in a study by Verstrynge et al.[12]While TMA wires maintain more constant forces during deactivation periods. Stainless steel wires can sustain higher loads of force before fracture than the TMA wires.[24]Nitrogen ion implantation procedure showed an extremely hard surface layer of TMA wires that would improve fatigue resistance, ductility and reduction in the coefficient of friction in vitro was noted by Kusy et al.[15]However the rate of space closure by sliding mechanics via nitrogen ion implantation was similar to stainless steel, reported by Kula et al in his in vivo study.[14]

Since after the coating has been done there will be an increase in the thickness of the archwire as concluded by Zhang et al, which in turn is directly proportional to the frictional values that is generated during the sliding mechanics.[41]After coating there was an increase in the thickness and surface hardness of TMA archwires of 0.017 x 0.025 and 0.019 x 0.025 inch as reported by Burstone et al.[13]Stainless steel archwires of dimensions 0.017 x 0.025 and 0.019 x 0.025 inch showed increase in the thickness after the coating procedure was done.[22]

Tooth moves in the alveolar socket where the force that is applied exceeds the resistance offered by the periodontium and the frictional forces in the bracket. An optimal force application will result in rapid tooth movement by appropriate tissue response.[24]The cellular activity is stimulated in the periodontal ligament when light continous forces are applied rather than higher forces that causes the occluding of the blood vessels in the periodontal ligament. During the initial phase, the delivered force in sufficient to overcome the frictional forces.[27]But as the treatment progress, it becomes essential that the delivered force overcomes the resistance of the modified periodontal supporting structures. Because of the friction, the sliding of the wire along the bracket will cause a fall in the original force levels that is applied to achieve proper tooth movement.[65]

Tselpsis et al stated that the friction occurred with angulation of arch wire to bracket and that the lubrication significantly, lowered friction. The study quantified the frictional force values of sliding between various orthodontic brackets and archwires.[3]Ahmed et al, stated that whether friction is to be considered as a boon or is it to be avoided in the orthodontic treatment.[75]

Mostly in orthodontics we use type 304 austenitic stainless steel. One of the key properties of any stainless steel alloy is it's resistance to corrosion. High temperature can compromise the oxidation resistance of the stainless steel alloys, leading them to become rusted and weakening their structural integrity.[85]

The significance of the melting temperature ranges of the stainless steel alloy has been given by the British stainless steel association stating that it influences the creep strength, oxidation resistance.[86]

Previous studies by Pacheco et al, showed that when rectangular wires was tested with active self -ligating brackets, significantly higher friction was shown than passive self-ligatingbrackets.[64]Miles et al, explained and discussed about the differences, advantages and disadvantages between the active and passive self-ligating brackets.[51]Owing to the advantage of having low friction, passive self-ligating brackets was selected for the present study.

Ehsani et al , stated that on comparison with the conventional brackets, self-ligation brackets had less friction.[56]Stefanos et al concluded in his study the friction was reduced when elastomeric modules was compared with any other conventional mode of ligation and also with respect to active self-ligating brackets.[60]The passive self-ligating brackets have lower static and dynamic sliding resistance than the active self- ligating brackets with 0.019 x 0.025 inch stainless steel wire.[53]Friction is the result of various influences and the self-ligation reduces frictional resistance much better when compared to the conventional mode of ligation as reported by Pizzoni et al.[38]

The 0.022 x0.028 inch passive self-ligating stainless steel brackets, MBT prescription were selected for the study ,because the pre adjusted edgewise appliance performs best in 0.022 x 0.028 inch form and is technique sensitive.[70]Space closure control using rectangular archwires is best accomplished without major archwire deflection by the MBT than any other systems. During the treatment with the pre adjusted edgewise appliance, the friction that occurs between the bracket and the archwire, during space closure in sliding mechanics plays a critical role in determining the rate of tooth movement and the archwire requirement.[87]

Surface roughness influences friction more directly in dry state. Rough surfaces causes considerable friction because of the contact between the interlocking of the archwire and brakcet.[63,68]Surface irregularities can also be attributed to the manufacturing process.[88]Surface characteristics is associated with the corrosion behaviours, biocompatibility and sliding movement. Surface treatment improves surface roughness of the archwires and enhances sliding.[66]

The physical vapor deposition by DC magnetron sputtering method produced a homogenous coating on the archwires.[18]The colour stability of AgNP coating on the archwires is yet to be evaluated clinically because with time colour may change and that the coating might split during it's use orally and may expose the metal underneath in case of aesthetic or coated archwires.[67]The surface quality affects the surface contact, esthetic result, the corrosion behavior, plaque accumulation and the biocompatitbility.[89]An important factor that influences the surfaces topography is the technique of coating on the archwires. Surface topography plays a role by critically modifying the efficiency of the orthodontic components, determining the effectiveness of the archwire guided tooth movement.[90]However little information is available in the literature to denote the surface changes after oral exposure.

Other studies that showed coatings on archwires with improvement in the frictional values were by Krishnan et al, in which WC/C (Tungsten carbide /carbon) coated TMA archwires using cathodic arc PVD and magnetron sputtering ,with their thin nature and smooth surface showed low frictional properties on comparison with uncoated and coated titanium aluminium nitride archwires making it ideal for space closure stage of orthodontic mechanics, when sliding mechanics isused.[19]

Zhang et al, evaluated and compared the diamond like nanosized carbon (DLC) coating and the effect of nitrocarburizing on the values of frictional forces and stainless steel archwires biocompatibility. DLC coating and nitrocarburizing showed great improvement in the surface hardness of the wires, low friction and good biocompatibility. The nanostructured DLC coating provided much better corrosion resistance and elasticity, the nitro carburizing procedure exhibited substantial improvement in the frictional properties.[41]

According to Katz et al, coating of a self-lubricating metal containing fullerene-like WS2 (IF) nanoparticles was done and it was found to have significantly reduced archwire friction.[9]In another study by Redlich et al, coating was done as the stainless steel wires were introduced into electroless solutions of nickel–phosphorus and inorganic fullerene-like nanoparticles of tungsten disulphide. It produced a significant reduction in friction , coefficient changed from 0.25 to 0.08, while the friction forces decreased by 54 per cent.[23]Farronato et al, stated that teflon coating on twelve types of archwires, showed significant reduction in the coefficient of friction.[62]

The surface treatment can reduce friction by 46%.[15]Studies have shown the effect of fluoride treatment on the surface of stainless steel and beta titanium could bring about reduction in the mechanical characteristics and also surface irregularities on the surfaces of the archwires.[49]Previous studies showed that **t**he beta titanium archwires treated with nitrogen ion implantation showed improvement in friction**,t**he frictional properties and surface characteristics for honey dew TMA wires was statistically significant being less than purple coloured TMA wires. Both the coloured TMA wires showed low frictional force values and surface roughness than TMA wires that were uncoated as studied by Aloysius et al.[77]The present study was found to be consistent with these concurrent studies which stated that there was improvement in the reduction of frictional values once coating was done on the archwires.

Arash et al ,reported the electroplating of silver on stainless steel brackets did not show any reduction in friction but an increase in friction was noted. In his study, it was mentioned about the possibility of reduction in friction once PVD coating of silver was done on the stainless steel brackets.[17]Hence this study was initiated to ascertain whether there was any reduction in frictional values and instead of coating the stainless steel brackets, the archwires were coated as no other studies have clearly reported coating of silver nanoparticles on archwires used in orthodontics. The findings of the present study confirms that there is no reduction in friction with stainless steel archwires when coated with AgNP, rather an increase in friction was found and is consistent with the study stated by Arash et al.[17]

The deposition of silver nanoparticles on rectangular beta titanium archwires makes it possible to use larger archwires, with reduced friction, ensuring much better predictability of tooth movement.[78]In the present study, TMA and stainless steel archwires were coated silver nanoparticles, which is highly potent antibacterial in nature as already reportedin other studies.[80-82]Nano silver is the new generation of nano product in biomedical and dental application. Silver nanoparticles comprises of silver atoms ranging in 1 to 100nm diameter and are now applied in several areas of dentistry with an aim to increase the oral health.[84]

Because of their small size, AgNPs shows chemical, physical and biological properties different from their bulk materials. Silver nanoparticles has been found that they also have antiviralproperties.[81] The nanotechnology helps in the production of silver nanoparticles with more surface area to volume ratios, increased potency against bacteria , being less toxic to humans.It also prevented or reduced the formation of biofilm over dental material surfaces as stated by Julianna, et al .[21]

Among the commercially available nanosized materials, nanosilver is the most used nanocompound in the medical field.[61]The silver nanoparticle coating for the present study is done through the physical vapor deposition method. It bears an advantage due to its easy availability and relatively low temperature of coating 200^0C which is far below the melting range of TMA and stainless steel wires.

Krishnan et al stated the essentiality of keeping the temperature during the coating procedure at relatively low levels to maintain the mechanical properties at a constant level during coating of the archwires . As the temperature was kept at 200^0c during the heating process, it was found not to have affected the mechanical properties of the beta titanium alloys, as it never crossed the melting range of the alloy.[19]

In the present study, surface characteristics was evaluated by scanning electron microscope and profilometry. The Profilometry was carried out to assess the thickness of the coating of AgNP on the archwires. It was found to be of ~ 700 nm thickness. SEM was used to evaluate the surface qualities of the archwires coated with AgNP and uncoated wires before and after the friction testing. The roughness of the material can also affect the esthetics of the appliance, coefficient of friction.[66]Studies have shown that uniform coating thickness was not attained by esthetic coated archwires when evaluated using scanning electron microscope .[67]Other SEM studies by Zhang et al, results shows successful deposition of even and dense nanostructured DLC films onto orthodontic stainless steel archwires. The ultrafine grains and wider atomic spacing resulting from the nanostructured DLC film, provided excellent characteristics compared with traditional archwires.[41]

Krishnan et al , studied that all three archwires groups used , exhibited no significant surface changes from its pre frictional evaluation form when observed through environmental scanning electron microscope.[19]Arashet al, SEM results concluded that the silver coatings had a uniform thickness of about 8–10 µm. There were surface irregularities on bracket surface before coating.The surface of the bracket was smooth after coating.[17]

The present study reports are consistent with these concurrent studies stating that, there was uniform deposition of AgNP on the archwires and that the coating remained intact even after friction testing. The SEM results in the present study showed no significant surface alterations in the post tested AgNP coated stainless steel and beta titanium archwires (SEM figures - 2,4,6,8). The surface structure of archwires depends on the complex manufacturing process, the surface finish treatments and the alloys used. The study showed that AgNP coated archwires were smooth and homogenous (SEM figures – 1,3,5,7). It was found that the AgNp coated 0.017 x0.025 inch TMA showed the most smooth surface followed by coated 0.019 x0.025 inch TMA , AgNP coated 0.017 x 0.025 inch stainless steel , coated 0.019 x0.025 inch stainless steel,0.017 x 0.025 inch uncoated stainless steel , 0.019 x 0.025 inch uncoated stainless steel , .The most surface roughness was observed in uncoated 0.019 x0.025 inch TMA followed by uncoated 0.017 x 0.025 inch TMA.

This study has focussed mainly on the frictional properties of the archwires, as to whether there is any significant change after the AgNP coating has been done on the stainless steel and beta titanium archwires. The uncoated stainless steel archwires had smooth surface and beta titanium archwires had rough surface after testing and there seem to have even distribution of AgNPs after the coating procedure.

On comparison the P value of 0.56 indicated no significant difference when compared Group-IA with Group-IB ($p>0.05$). P value of 0.67 showed no significant difference when compared Group-IC with Group-ID ($p>0.05$).As$p>0.05$, no significant difference was found when compared between the subgroups of Group-I. P value of 0.04 states a significant difference when compared Group-IIA with Group-IIB ($p <0.05$).P value of 0.04 showed significant when compared Group-IIC with Group-IID ($p <0.05$); $p<0.05$ significant when compared Group-IIA with other groups; $p<0.05$ significant when compared Group-IIB with other groups; $p<0.05$ significant when compared Group-IA with other groups, $p<0.05$ significant when compared Group-IB with other groups; $p<0.05$ significant when compared Group-IC with other groups; $p<0.05$ significant when compared Group-ID with other groups; $p<0.05$ significant when compared Group-ID with other groups; $p<0.05$ significant when compared Group-IIA with other groups; $p<0.05$ significant when compared Group-IIB with other groups; $p<0.05$ significant when compared Group-IIC with other groups; $p<0.05$ significant when compared Group-IID with other groups. These results clearly indicate that the frictional values were reduced for beta titanium archwires once coating was done and an increase in friction occurred in the case of stainless steel coated archwires.

Deposition of AgNP films on the archwires using PVD – DC magnetron sputtering lead to a reduction in the surface irregularities of the archwires with no significant effect on the archwire strength.

In the present study when AgNp was coated on beta titanium archwires,0.017 x 0.025 inch TMA showed the least frictional value among other groups and 0.019 x0.025 inch TMA wire also showed less frictional value when compared with the uncoated counterpart . Coated stainless steel archwires showed no statistical reduction in frictional values .It could be inferred that TMA archwires coated with AgNP film could be utilized for the sliding mechanics, as the surface coating has definitely shown to reduce the friction compared with the uncoated form.

Another significant finding of this study is that, the frictional values of AgNP film coated stainless steel archwires has not shown any reduction in friction values, but an increase in the friction is noted. Here the tribological characteristics of the AgNP film did not reduce the friction on stainless steel archwires on both dimensions used.[91]

Probably decreasing the coating layer thickness would probably reduce the friction in the stainless steel archwire.Various factors play a vital role in determining the reduction of friction in coated archwires like the substrate characteristics, deposition thicknes , rigidity of the substrate, atom to atom interaction of the substrate and the nanoparticle film ,adhesion sticking coefficient which could be confirmed through scratch test. Mahieu et al stated that sticking coefficient decreases with the decrease in target – substrate distance which is used for the coating procedure and that it leads to an increase in the deposition effect which depends on the deposition thickness and the conditions, energy flux in the growth of thin films is also an important factor.[55]

The effective sticking coefficient could also be influenced by the substrate surface temperature .Higher substrate temperature will result in higher deposition rate, reducing the effective sticking coefficient. To note into consideration, other methods of physical vapor deposition methods might be utilized, as in this study a temperature of 200°C was used for both the types of archwires . But the deposition of AgNPs has proved effective for the beta titanium archwires in reducing the frictional values. Dc –

magnetron sputtering was used in this study because of the high deposition rates ,ease of sputtering of metals in nanometric scale, synthesizing increased purity films , very good adherence of the films , improved and very good coverage of steps, ability to coat heat sensitive and large – area substrate ,ease of automation and one of the simplest application of the magnetron that is widely used as stated by Swann et al.[39]

This present study has shown that there is no need to coat AgNP film on stainless steel archwires, as there is only an increase in the friction when tested as the tribological characteristics has shown to be ineffective.[91]Further test via any other method of physical vapor deposition with varying deposition thickness or in vivo study could be carried out in future.

CONCLUSION

The deposition of silver nano particles on 0.017 x 0.025 and 0.019 x 0.025 inch TMA, 0.017 x 0.025 and 0.019 x 0.025 inch SS archwires through physical vapor deposition has contributed in decreasing the surface roughness. Based on the statistical evaluation of the data obtained, the following conclusions were drawn:

a) Among the two groups compared , the 0.017 x 0.025 inch TMA coated with AgNP showed the least frictional resistance, which proved statistically significant ($P<0.05$)

b) The highest frictional resistance was offered by the uncoated TMA wire – 0.019 x 0.025 inch TMA.

c) There is no significant reduction in friction when SS archwires was coated with AgNP.

d) There was significant reduction in friction when TMA wires were coated with AgNP.

e) 0.019 x 0.025 inch TMA uncoated showed significant difference, on comparison with other groups ($P>0.05$).

f) Silver nanoparticles coated TMA archwires may be used during the space closure stage of orthodontic movement of teeth where sliding mechanics in used.

g) At a magnification of 3000 X , width of 10mm there is no significant difference between the pretested and post tested AgNP coated samples of beta titanium archwires, the control uncoated sample of both 0.017 x 0.025 and 0.019 x 0.025inch beta titanium archwires shows significant surface irregularities owing to the presence of high friction during the friction testing.

The AgNP coated stainless steel archwires shows no significant surface alterations in the Post tested samples, apart from minor vertical lines and irregularities in the Post tested samples.0.017 x 0.025 inch stainless steel shows debris adherence in relation to the post tested AgNP coated sample , probably the adherence of fibres of cotton used to clean the sample prior to testing .The control uncoated stainless steel samples had no significant difference in the surface characteristic once the friction test was done.

The highest surface irregularities were found to be for 0.019 x 0.025 inch uncoated TMA archwires and the least for AgNP coated 0.017 x 0.025 inch TMA archwires.

h) No Peeling off the AgNP coated layer was observed in either test group I or in test group II after the friction test.

i) The coating thickness is uniform and even, measuring upto ~700nm.

A myriad of biomaterials and procedures have been implemented to alter the surfaces of components of orthodontic appliances. For selecting the most appropriate archwires for the patient, clinicians should consider the demerits of both the surface quality and sliding resistance for betterment and faster treatment.

Thus it can be concluded through this present study that AgNP coated TMA archwires could definitely reduce the frictional values as observed during the friction testing procedure .There was no significant statistical difference in the sliding force values between AgNP coated stainless steel archwire and uncoated stainless steel archwires of both dimensions used in this study . So there is no need to coat AgNp on stainless steel archwires.

Nano orthodontics is in its preliminary stages of development and its applications are limited to the development of nano materials. The merging of nanotechnology with orthodontics would help the clinicians in improving the quality of patient health and care and its applications should further be extended as the promise of such a technology has a strong potential to revolutionize the field of orthodontics.

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ANNEXURE

SREE MOOKAMBIKA INSTITUTE OF DENTAL SCIENCES

KULASEKHARAM, KANYAKUMARI DIST., TAMIL NADU, INDIA.

INSTITUTIONAL RESEARCH COMMITTEE

Certificate

This is to certify that the research project protocol, ***Ref no. 01/07/2016*** titled, ***"An in vitro study to evaluate the frictional characteristics and surface topography of two different archwires coated with silver nanoparticles using passive self ligating brackets"*** submitted by ***Dr. Surya R. Krishnan, II Year MDS, Department of Orthodontics and Dentofacial Orthopaedics*** *has* been approved by the Institutional Research Committee at its meeting held on ***19^{th} July 2016.***

Convener
Dr. T. Sreelal

Secretary
Dr. Pradeesh Sathyan

INSTITUTIONAL HUMAN ETHICS COMMITTEE

SREE MOOKAMBIKA INSTITUTE OF MEDICAL SCIENCES,
KULASEKHARAM, TAMILNADU

Communication of Decision of the Institutional Human Ethics Committee(IHEC)

SMIMS/IHEC No: 1 /Protocol no: 6 /2016

Protocol title: An in vitro study to evaluate the frictional characteristics and surface topography of two different arch wires coated with silver nanoparticles using passive self ligating brackets
Principal Investigator: Dr. Surya. R. Krishnan
Name& Address of Institution: Department of Orthodontics & Dentofacial Orthopedics Sree Mookambika Institute of Medical Sciences, Kulasekharam ☑ New review ☐ Revised review ☐ Expedited review
Date of review (D/M/Y): 14.12.2016 Date of previous review , if revised application:
Decision of the IHEC: ☑ Recommended ☐ Recommended with suggestions ☐ Revision ☐ Rejected
Suggestions/ Reasons/ Remarks:
Recommended for a period of : one year

Please note*

- Inform IHEC immediately in case of any Adverse events and Serious adverse events.
- Inform IHEC in case of any change of study procedure, site and investigator
- This permission is only for period mentioned above. Annual report to be submitted to IHEC.
- Members of IHEC have right to monitor the trial with prior intimation.

Renugagangadhar

Signature of Member Secretary(IHEC)

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Date:...29-Nov-17...

TO WHOM IT MAY CONCERN

This is to certify that mechanical testing of samples submitted by Dr. Surya R. Krishnan, Post graduate student of Department of Orthodontics and Dentofacial Orthopedics, Sree Mookambika Institute of Dental Sciences, Kulasekharam, Kanyakumari District, Tamil Nadu was done at the Division of Polymeric Medical Devices, Sree Chitra Tirunal Institute of Medical Sciences and Technology, Poojappura, Trivandrum. Her samples were tested for Frictional Resistance. The testing was done for her thesis work entitled, '**AN IN VITRO STUDY TO EVALUATE THE FRICTIONAL CHARACTERISTICS AND SURFACE TOPOGRAPHY OF TWO DIFFERENT ARCH WIRES COATED WITH SILVER NANOPARTICLES USING PASSIVE SELF LIGATING BRACKETS**'.

Roy Joseph

Dr. Roy Joseph
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26th October 2017

TO WHOMSOEVER IT MAY CONCERN

This is to certify that **Dr. Surya. R.Krishnan**, Final Year Post Graduate student, Department of Orthodontics and Dentofacial Orthopedics from Sree Mookambika Institute of Dental Sciences, Kulashekharam, Kanyakumari Dist. Tamil Nadu had conducted experiments for depositing silver nanocrytalline thin film of ~700 nm thickness at the substrate temperature of 473 K on two different types of archwires using the DC magnetron sputtering technique. She has visited our Centre for Nanoscience and Nanotechnology (CNSNT), Sathyabama University, Chennai on 24/10/2017 and carried out research activity till 26/10/2017 during office hours as a part of her academic project activity.

(Dr. P. Kuppusami)

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Ref:

Date 9.11.2017........

Certificate

This is to certify that **Dr.Surya.R. Krishnan** (Post Graduate Student, In Department of Orthodontics and Dento facial Orthopedics at Sree Mookambika Institute of Dental Sciences, Kulasekaram) has carried out Scanning Electron Microscopy analysis in our lab as a part of her MDS dissertation titled **"An Invitro Study to Evaluate the Frictional Characteristics and Surface Topography of Two Different Archwires Coated with Silver NanoParticles Using Passive Self ligating Brackets."**.

Dr Manoj Komath
Scientist-in-Charge
SEM Lab

,